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FOSSILS

What They Tell Us of Plants and Animals of the Past

By Richard Swann Lull, Ph. D., Sc. D.

STERLING PROFESSOR OF PALEONTOLOGY AND DIRECTOR OF
PEABODY MUSEUM, YALE UNIVERSITY

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CONTENTS

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Dedicated
To the Memory of
OTHNIEL CHARLES MARSH
Pioneer Paleontologist
Who assembled and presented
the great collections at Yale

PREFACE

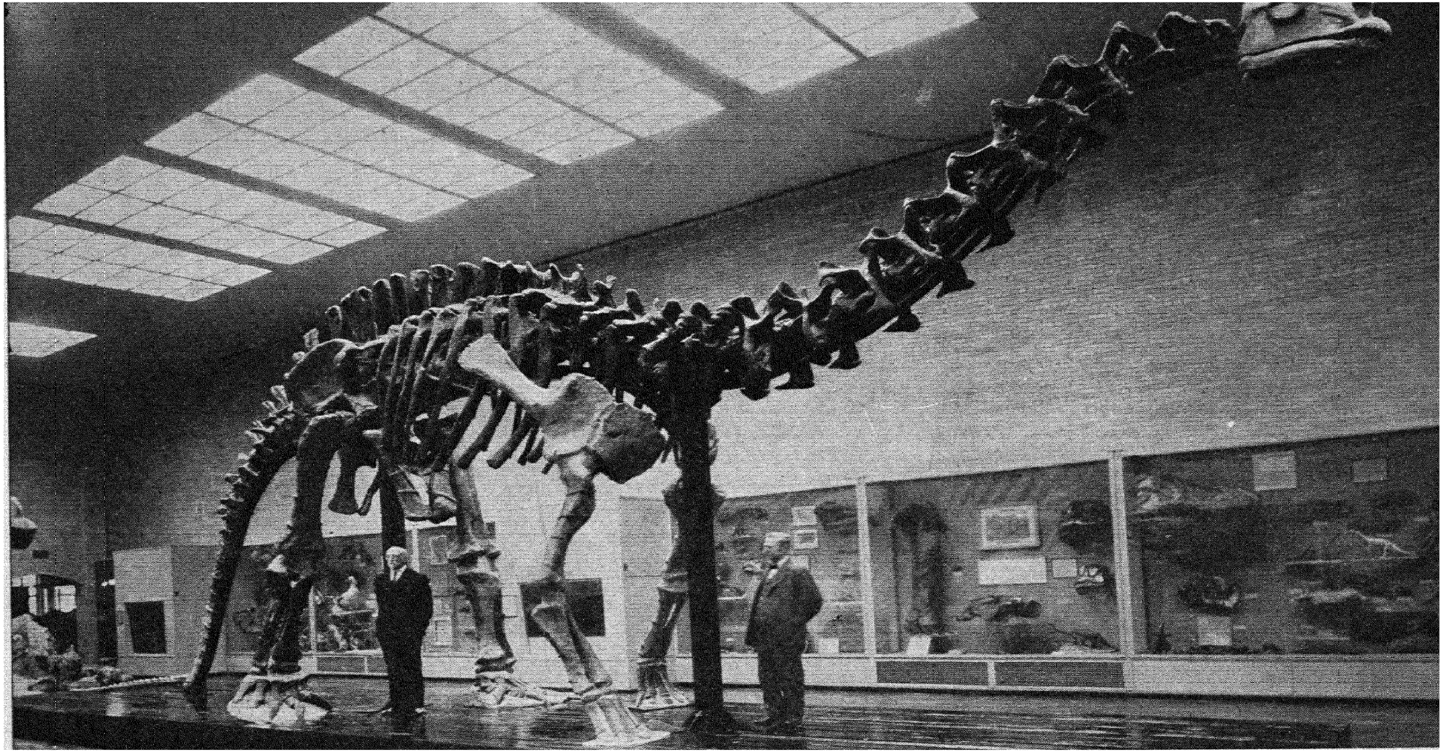
TO WRITE a book on Fossils that would appeal to the average person by reason of its satisfying interest as well as by its instructive qualities was a somewhat serious undertaking, but the endeavor has proved an intriguing task.

The story of Fossils—what they are and what they teach—is a thoroughly fascinating one, and involves a great deal more of real interest to every one of us than is generally realized. When we consider that Fossils constitute all of our documentary evidence concerning the character and evolution of the plants, animals, and men of prehistory we see how very necessary is this study to any correct knowledge and understanding of life, past and present.

I am greatly indebted to my publishers for their sympathetic appreciation of the task they have assigned me, but especially to my colleague, Professor Carl O. Dunbar, who has read and criticized the work, as well as to my research assistant, Miss Nelda E. Wright, who has prepared the manuscript for the press and aided materially in preparing the illustrations.

Yale University

November, 1931.



SKELETON OF BRONTOSAURUS AT YALE PEABODY MUSEUM

Nearly 70 feet long, 16 feet high, and weighs 6½ tons; it was found at Como Bluff, Wyoming, and is probably 120,000,000 years old

The author is standing under the great reptile on the left

CHAPTER I

THE SIGNIFICANCE OF FOSSILS

IN THE ancient city of Verona there is a most admirably preserved Roman amphitheater, which was begun during the reign of the emperor Diocletian,* and which after falling into partial ruin was restored in the sixteenth century by Leonardo da Vinci. Most of us look upon the latter as an inspired painter and sculptor, and his *Last Supper,* painted on the walls of the chapel at the convent church of Santa Maria delle Grazie in Milan, is still one of the loveliest things ever created by the hand of man. But Leonardo da Vinci was also noted both as an architect and as an engineer; he dug canals in northern Italy, and thus was familiar not only with the rocks of that region, but with their contents as well. It is said that occasionally the workmen called his attention to the shells and other comparable objects found in these rocks and brought them to him, asking what manner of things they were, and that he was among the first to recognize their true identity as relics of bygone animals. Here and there, embedded in the stones which formed the benches of the amphitheater, huge coiled ammonite shells† may still be seen, possibly some of the very specimens which the inspired eyes of Leonardo saw for the first time in their true significance.

ANCIENT INTERPRETATIONS OF FOSSILS

The ancients had very different ideas concerning these objects, and some of them bear recounting for their historic interest. Fossils were thought to be failures of a creative force within the earth, or caused by a "stone-making force," or a "formative quality," and so on; they were looked upon as mere mineral forms which by chance resembled shells or bones;

* Diocletian was emperor of Rome, 284-313 A.D.

† See Figure 9 in "The Earth" in this *Series.*

they were explained by such scholastic phrases as "fatty matter set into fermentation by heat," or of a "lapidific juice," or of a "seminal air," or of a "tumultuous movement of terrestrial exhalations"—none of which was really explanatory after all.

To call them "sports of nature," particularly if these "sports" indicated some inscrutable purpose of the Almighty, answered the question fairly well, especially as the word "inscrutable" dismissed them at once from further investigation by a pious mind.

Even when the shells were recognized as such, they were thought to have been left as relics of some bygone flood, for the ideas of vast antiquity and extinction had not yet dawned in the minds of men. An interesting specimen came to light at Oeningen, Baden, and was thought by its discoverer to represent a human victim of the flood. It was described as "Homo diluvii testis," and the following admonitory verse goes with it:

Oh sad remains of bone,
Frame of poor man of sin,
Soften the hearts and minds
Of sinful recent kin.

Huge elephantine bones were hung up in the churches and other public places for the edification of the faithful, as they were supposed to be relics of the giants mentioned in the Bible. From them Henrion drew up tables showing the dimensions of our antedeluvian forebears. In these Adam was recorded as 123 feet, 9 inches, and Eve as 118 feet, 9 inches, and 9 lines, tall!

Others saw in the fossils the work of the devil, either to mar the Creator's handiwork, or to tempt the unwary away from the straight and narrow path of revealed religion, or, although in the minds of some twentieth century people this might prove beneficial to humanity as a whole, to confuse scientists!

As a matter of fact, Leonardo was absolutely right, and although occasionally clay concretions and other purely mineral phenomena do look surprisingly like objects of organic origin, the genuine fossil can have no other than Leonardo's interpretation. Although some of them have certainly given rise to dispute among scientific men, this is due not at all to their actual character, for not only are they of immense interest and help

in deciphering the history of the globe, but their evidence, when correctly interpreted, is absolutely unassailable.

Fossils Visualize the Geologic Past

Fossils serve as the only means whereby we are able to visualize the past, for they are indicative of climates and of limitations of land and sea and give us all the discernible facts which we possess concerning plants, animals, and men, in the millions of years of geologic time. As such their story is not only an authentic but a deeply interesting one, and from no other source may this history be told.

Many have tried to discount fossil evidence, either through ignorance, prejudice, or because of the apparent difficulty of reconciling it with their religious beliefs. The same has been true of other great scientific generalizations as well, and men have suffered ostracism and mental and physical torment in the upholding and vindication of what has been accepted ultimately as the truth. I refer to the great controversial questions of medieval time, such as the form of the universe and the sphericity and movement of the earth in its orbit. That the truth of these great questions was later established without violence to religious faith shows that the facts taught by the fossil evidence will also come eventually into full acceptance.

Fossils Prove Evolution

The science of fossils stands as the final court of appeal when the doctrine of evolution is brought to the bar, for not only does it present an immense array of facts, not one of which is out of harmony with the evolutionary idea, but there is no other hypothesis ever conceived by man which can truly account for them. The only questions which can arise are those of interpretation, or of adequate restoration of missing parts, or of relationships of the organisms to one another, because these are often questions of opinion only; of the finally established facts which the fossils proclaim, we are as certain as we are of anything in this world.

CHAPTER II

THE NATURE AND ANTIQUITY OF FOSSILS

Definition of a Fossil

THE word fossil is derived from the Latin *fossilis,* which in turn comes from *fodere,* meaning to dig up, and in older usage implied anything which was dug out of the earth, whether mineral, rock, or organic in origin. Later the term was restricted to include the organic only and not the minerals or rocks.

The first prerequisite for fossilization is *natural burial,* and, as Huxley once said, the remains of a sheep buried under the silt of a recent flood would come, strictly speaking, under this head. Usually, however, antiquity is implied, and by geologists the term is confined to the remains of animals and plants which lived before the dawn of the Recent era.* The necessity for burial is obvious, for exposed remains of animals and plants usually decay. They must, therefore, be hermetically sealed, and, while they may remain either wet or dry, alternation between these two conditions tends to hasten oxidation and hence destruction not only of the soft parts but also of the hard parts. Usually those animals which have hard parts, such as limy shells and bones, are more readily preserved, but in certain rare circumstances the most delicate and fragile things, such as the remains of jellyfish, may leave a record almost as durable as time itself.

Classification of Fossils

Fossils are grouped under several convenient heads according to the manner of their preservation. It must be realized, however, that as the chances for such preservation are rare indeed today, so they must have been in bygone days. Thus the existing fossils must represent an extremely small fraction of the organisms which actually lived in the geologic past.

* See chart of "Geologic Chronology," pages 46-47.

Furthermore, those which have been discovered and collected represent again but a small percentage of those which yet lie buried in the earth's strata, or of those which did exist for a time only to be destroyed by the various natural agencies which are continuously fretting the surface of our globe. The several sorts into which fossils as such are conveniently divided are as follows:

(1) *Fossils Actually Preserved in Ice or Frozen Soil, in Oil, or in Amber*

The first of these include certain arctic animals, especially the hairy mammoth (*Elephas primigenius*), and the woolly rhinoceros (*Rhinoceros tichorhinus*) occasionally found within the confines of the arctic circle, in the Siberian tundras, and also, to some extent, in Alaska.

These are animals which succumbed during the period of glacial cold and, once frozen, have never subsequently thawed. Siberian mammoths occasionally come to light, such as the famous one discovered in the Lena delta in 1799, collected seven years later, and transferred to the St. Petersburg (now Leningrad) Museum where the mounted skeleton, with portions of

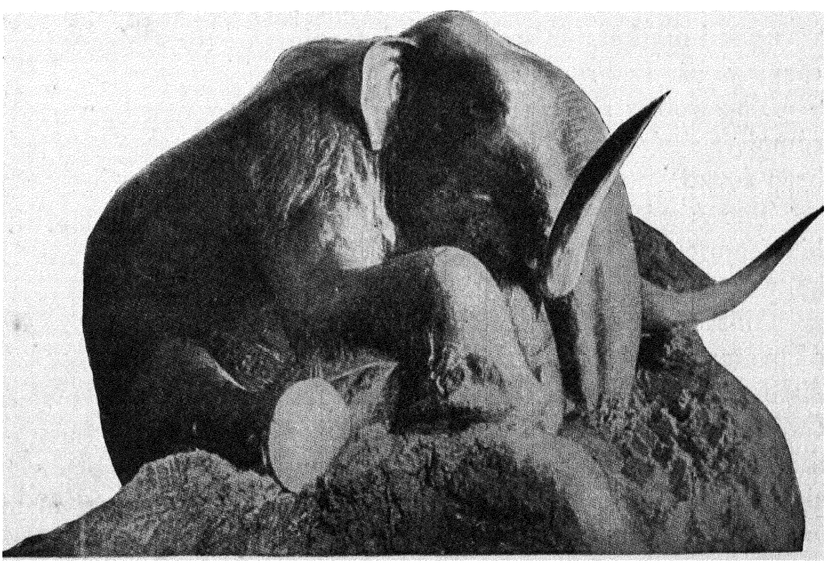


Fig. 1—THE BERESOVKA MAMMOTH FOUND FROZEN IN SIBERIA
Not only were the skeleton and hide intact, except for part of the exposed trunk, but also the flesh and the internal organs

the hide adhering, may still be seen. Another mammoth was discovered at Beresovka, Siberia, which lies some 800 miles west of Bering Strait and 60 miles within the arctic circle (Fig. 1). In this instance the animal was practically intact when discovered, except that the exposed trunk had been partially devoured by wolves. The natives hold such discoveries in superstitious awe and will have nothing to do with them; they will not even report a find to those who might recover the specimen. In this instance, however, an expedition from the St. Petersburg Museum arrived in time to secure the animal before it was too late. Not only were the skeleton and hide, except for the mutilated trunk, intact, but also much of the hair, together with the soft parts, flesh, and internal organs. In the chest there was a mass of clotted blood, and between the clenched teeth lay the last morsel of food, showing how quickly death had overtaken the victim. He had evidently slipped backward into a crevasse and made violent efforts to escape, as the clotted blood from a ruptured blood vessel and a broken hip and a broken forearm testify. One authority, Tolmachoff,* records no fewer than thirty-nine localities in northern Siberia where frozen carcasses were found between the years 1692 and 1923. In addition to these, thousands of tusks have been secured, of which a certain percent was good marketable ivory. In fact, most of the Chinese ivory carvings are from this source.

The woolly rhinoceros is rarer, and no museum possesses a complete skeleton, though several skulls with adhering skin have been found.

The Alaskan ice cliffs have yielded mammoth remains with hide, muscles, and the fat—somewhat altered into a material known as adipocere—but thus far no complete carcasses.

Oil-saturated soils have proved another, though rarer, means of preserval. In 1907 the carcass of an extinct rhinoceros was discovered in the oil and wax region near Bohorodcrany, eastern Galicia, Poland. Here the nasal horn, a foreleg, and much of the skin were found some six feet below the surface. There is also published the previous finding of a nearly complete mammoth in the same locality.

* Prof. I. V. Tolmachoff (1872-), Carnegie Museum, Pittsburgh, in *Transactions of the American Philosophical Society* (N. S.) XXIII, 1929.

Specimens of ground sloths (*Nothrotherium*) have been found in southwestern United States, especially at Gypsum Cave in New Mexico. At Aden Crater, also in New Mexico, a marvelously preserved specimen was discovered in an old volcanic vent 100 feet underground, buried in bat guano which had been accumulating for centuries. This skeleton, held in articulation

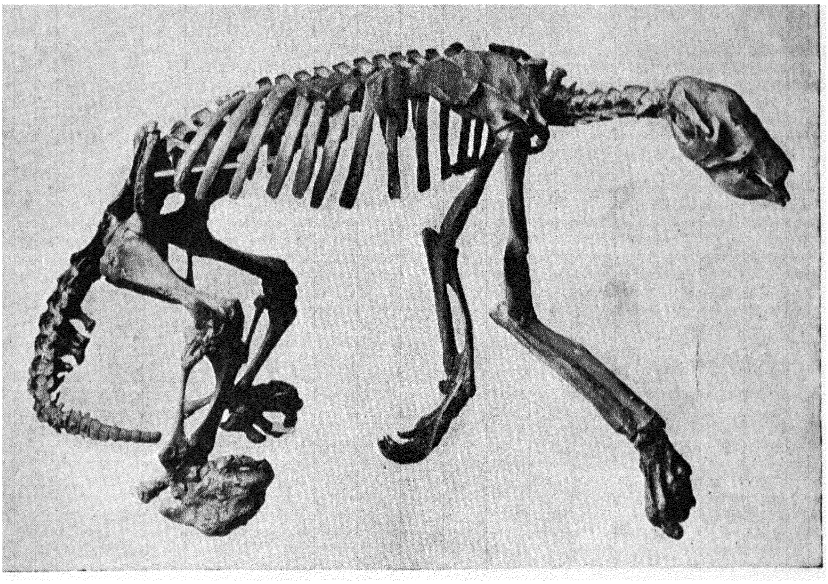


Fig. 2—THE GROUND SLOTH, *NOTHROTHERIUM*

Found at Aden Crater, New Mexico, in 1928. The skeleton is held in articulation by its tendons and sinews. It also retains the claws and portions of the hide and hair

(*After Lull*)

by its tendons and sinews, with the claws and portions of hide and hair still attached, is now in the Museum of Yale University (Fig. 2). Doubtless in these instances the extremely dry atmosphere desiccated the animal before extensive decay set in, the guano being merely contributory to the preservation.

In all of these cases where the original animal material is preserved, the creatures are of relatively recent age, geologically speaking, amounting to some thousands of years perhaps, but that is all. At any rate, the animals are all extinct and of a Pleistocene* character if not actually Pleistocene in time.

Yet another method of preserval is in amber, the fossil gum

* See chart of "Geologic Chronology," pages 46-47.

or resin which exuded from the trunk and limbs of pine trees, especially *Picea succinifera,* which lived in Europe during Oligocene* time. When first secreted, this resin was sufficiently soft to entrap and engulf such fragile forms as insects and spiders. Later, the more volatile portions of the gum having evaporated, it hardened into amber without doing the slightest damage to the contained creatures, which are preserved with body, wings, and even the most delicate hairs entire. The amber itself may also be considered a fossil, and hence both the medium and the preserved object come under the same general heading.

Courtesy of Dr. Carl Dunbar

Fig. 3—AN ANT ENCLOSED IN A PIECE OF AMBER

The amber is the hardened gum which exuded from the trunk of certain pine trees in Oligocene time

Most of our knowledge of fossil ants is derived from amber-preserved specimens (Fig. 3); of insects in general and spiders about two thousand species are known from this source, as well as over a hundred species of plants. The Baltic amber is found about Königsberg and along the coast of Samland, Germany. The action of the sea washes away the sediments and leaves the amber pebbles exposed on the beach. They have been a valuable commercial product for many years.

(2) *Petrification*

The term petrification (*i.e.,* turning to stone) is so often used by the uninformed as though it were synonymous with fossilization that it is well to make the matter clear. A petrification is a fossil. On the other hand, there are many fossils which are in no sense petrified—hence the terms are not coextensive. Petrification applies to those fossils in which the animal matter is partly or wholly replaced by some mineralizing substance, such as iron oxide, pyrites, sulphur, malachite, magnesite, carbon, or silica. At first a bone or shell, for instance, loses its animal matter, leaving behind the calcium phosphate mineral matter only. Then infiltrating water, carrying the

* See chart of "Geologic Chronology," pages 46-47.

petrifying agent in solution, gradually invades the object, filling the spaces which the animal matter formerly occupied, and the specimen gains noticeably in weight, although the original material is still there and its structure, even in minute detail, is unimpaired. The greater part of fossil bones of Cenozoic* mammals, if not all of them, are in this state. Even the bones of dinosaurs of the Mesozoic,* whose age is measured in tens of millions of years, have still enough of their original phosphates left to form food for plants, whose roots sometimes penetrate and aid in disintegrating the bone. Later the specimen may be entirely replaced, and one gets what is known as a *pseudomorph,* which preserves the general form of the original object but not its minute structure. (See Figure 26, on page 48.)

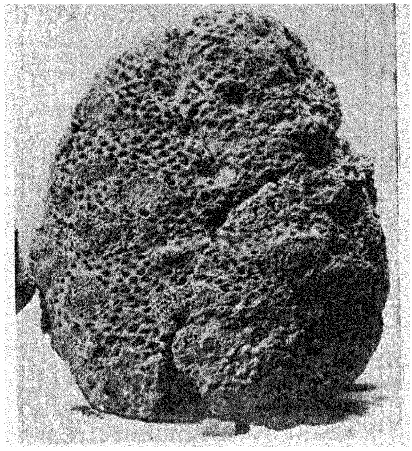


Fig. 4—A CYCAD TRUNK (*Cycadeoidea colossalis*)

From the Cycad National Monument, near Edgemont, South Dakota. Some of these petrified stems reach a weight of 800 pounds

Another phase of petrification is histometabasis,† or molecular replacement. In this process, as the original material disappears, it is replaced molecule for molecule by the petrifying agent, so that not only is the external form preserved but the minute or histologic structure as well. Obviously this replacement must precede any decay, otherwise the detailed structure would be lost. Hence its rarity in animals as compared with

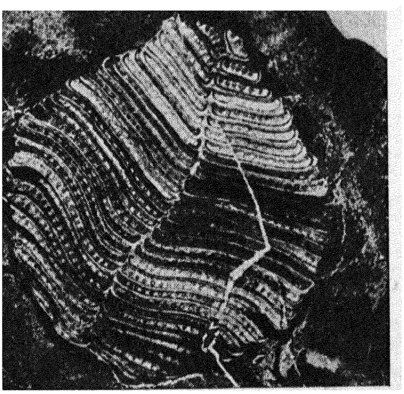


Fig. 5—SECTION OF A FOSSIL CYCAD

Showing the detailed structure of a young undeveloped frond

* See chart of "Geologic Chronology," pages 46-47.

† From two Greek words, *histon,* meaning tissue, and *metabasis,* meaning exchange.

plants, because the rate of disintegration of the former is so much more rapid.

The fossil cycads, allied to the existing sago palms, which are found in such perfection in Mesozoic* rocks, are remarkable instances of histometabasis, for not only will a thin section of the trunk exhibit wonderful details of structure beneath the microscope, but by sectioning the developing buds, the long vanished foliage, as well as the flowers, may be reconstructed with scientific precision.† (See Figures 4 and 5.)

Although the term histometabasis is usually applied to plant tissues, some remarkable instances of comparable preservation of animal remains have also come to light. Thus, from the shales of Devonian age found near Cleveland, Ohio, the American zoologist, Bashford Dean (1867-1928), demonstrated not only the flesh but even the kidneys of fossil sharks of the genus *Cladoselache.* He illustrated the miscroscopic structure of Cladoselachian muscle as compared with that from an existing shark, and even the cross striation (lines) of the fibers, characteristic of the voluntary muscles, as well as the delicate sarcolemma, or fiber sheath, is as clearly visible in the one as in the other.

With the passing of time, petrifications may suffer further change, for the replacing material tends to rearrange its molecules according to the laws of crystals. First, the minute structure may be destroyed, and ultimately, after an immense lapse of time, the external form may become modified or obscured until all trace of organic origin is lost.

(3) *Natural Molds or Casts*

Another type of fossil consists of natural molds or casts of the plant or animal, with no trace of the original material retained. Sometimes a shell will be imbedded in sediment which not only preserves the form of the exterior but that of the interior as well. Percolating waters may dissolve out the actual shell, leaving a mold in the form of a cavity, from which a wax impression may be taken, reproducing the vanished fossil with admirable fidelity. In this way the skin impressions of certain dinosaurs have been preserved (Fig. 6). For instance,

* See chart of "Geologic Chronology," pages 46-47.
† See Figure 29 on page 29 of "The Plant World" in this *Series.*

the animal dies and its carcass settles into soft mud; the latter takes a perfect mold or impression of the hide with all the details

Courtesy of the Geological Survey of Canada

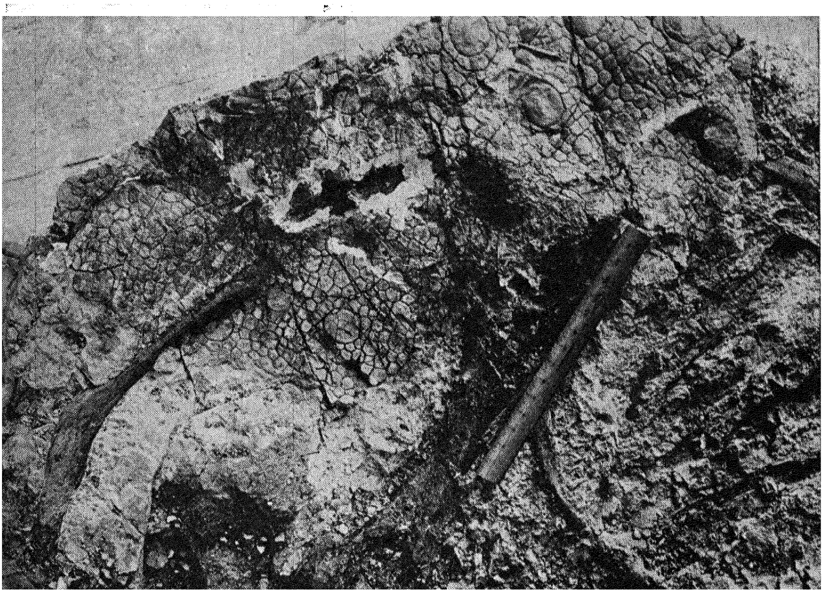


Fig. 6—THE SKIN IMPRESSION OF *CHASMOSAURUS*, A HORNED DINOSAUR
It lived in the Great West during Cretaceous time

of its scales or armor. In time, the hide decays and its place is taken by water-borne sands which, hardening, reproduce in sandstone a perfect replica of the exterior of the animal even to the minutest detail. Thus we have a natural cast comparable to our artificial one in the case of the shell.

Sometimes, when only a portion of the bone is preserved, as for example in fossil fishes, or in the Miocene dolphin to be seen in the Peabody Museum, more can be learned by removing the bone and taking a cast of the imprints in the matrix than by studying the ill-preserved bone itself. A classic instance of this occurred in Pompeii. When it was overwhelmed by volcanic ash from Vesuvius in 79 A.D., many were the victims, both men and animals, and later, as their bones were found they were at first merely dug out, until it was noticed that they lay in cavities in the hardened ash. The excavators then poured in liquid plaster of Paris, which, on hardening, was removed and found to show, with amazing fidelity, the body form and lineaments

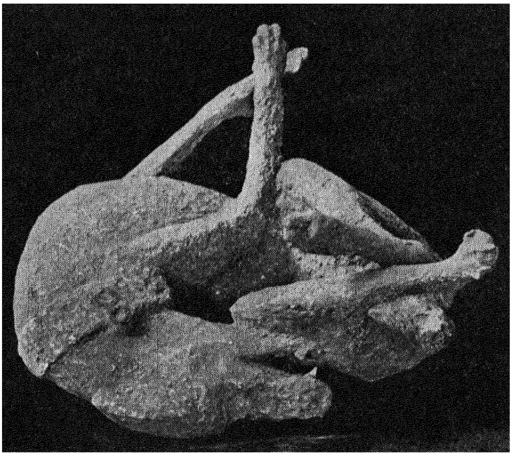


Fig. 7—THE CAST OF A DOG FOUND IN THE RUINS OF POMPEII

When the bones of the victims were found to lie in cavities in the hardened volcanic ash, plaster of Paris was poured in, which on removal, gave the exact body form

of the features of the people of Pompeii. Racial characters of Roman or Ethiopian, the garments girded about the loins, the expectant mother, another with her child in her arms—all lend an aspect of reality which otherwise would have been lost. Natural filling in of the brain cases of animals and of prehistoric men—endocranial casts—has given us valuable clues to the development of senses and of psychic characters, which otherwise would have been largely unknown except by inference.

Even so evanescent a thing as a jellyfish, which, as it possesses but from 1 to 4 percent of solid matter, soon evaporates when cast up on a beach, may, if immediately buried by sediment before the heat of the sun has destroyed its form, leave behind as enduring a mold as a shell or bone. Many of these have come to light, some being of very great antiquity (Fig. 8). Famous localities are the lithographic quarries in Bavaria (see page 28).

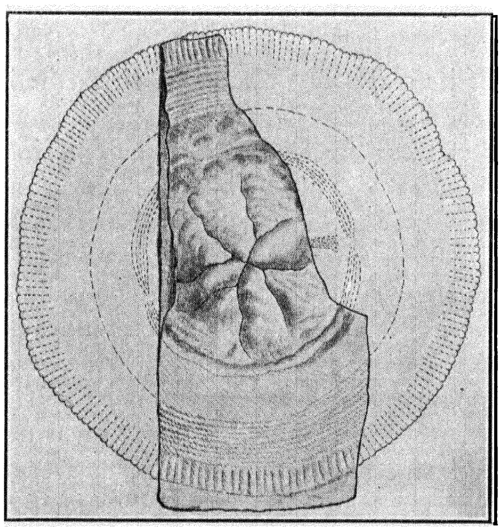


Fig. 8—IMPRESSION OF A FOSSIL JELLYFISH *RHIZOSTOMITES ADMIRANDUS*

Found in the lithographic slates of Eichstädt, Bavaria. The missing parts are restored in outline

(*Redrawn from Eastman-Zittel*)

(4) *Fossil Footprints and Trails*

Allied to the casts and molds are the footprints and trails of creatures, both vertebrate and invertebrate. Some of the most ancient indications of animal life are the obscure trails and burrows, presumably formed by worms, in the Proterozoic rocks. There are also trails of trilobites and other long-vanished crustaceans, of insects, and above all, of vertebrates, dinosaurs, and other reptiles, such as the thousands which have been discovered in the Triassic rocks of the Connecticut Valley.

For some reason, with rare exceptions, footprints and actual bones do not occur together, with the result that the matter of interpretation of the tracks and of visualizing their makers is often a problem of great difficulty. Footprints have an alluring interest, however, for they are relics of the living animals, while the bones are always those of the dead. If our interpretation is correct, a single footprint, called *Thinopus antiquus* (Fig. 9), from the Upper Devonian region of Pennsylvania, and now in the Peabody Museum, is the first indication of a terrestrial air-breathing vertebrate, antedating in antiquity by some millions of

Fig. 9—THE FOOTPRINT OF *THINOPUS ANTIQUUS*

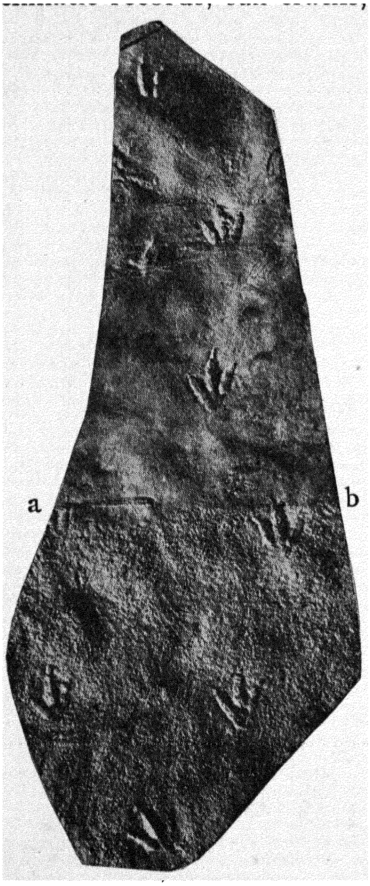
On the right is the footprint, supposedly the first indication of a terrestrial air-breathing vertebrate. On the left is a plaster mold of the footprint showing the same in relief

(After Lull)

years the actual bone remains discovered to date! It is significant in that it marked the emergence of the ancestors of all land-living, backboned creatures from the old limiting aquatic en-

vironment and thus made possible the peopling of our globe with the four higher classes of vertebrates, including man himself.

Accompanying the footprints are often meteorological and climatic records, sun cracks, ripple marks, and rain impressions (Fig. 10), which enable one to visualize something of the environment of the track-makers, if not the track-makers themselves. As with molds and casts we get either the intaglio-like footprint impressed by the animal, or, if it be the overlying strata, a cameo-like cast of the foot in relief; often both are preserved.



The line a-b shows the end of the strand; above it, the footprints have been made under water; below the line was dry sand with imprints of raindrops

(*After Hitchcock*)

Footprint specimens may be isolated tracks, or they may form a series. The latter are the more instructive, as they not only tell of the size and form of the foot, but of the posture, the varied gaits, and the length of limb; from occasional handprints of dinosaurs, the feeding habits, whether plant or flesh, may be deduced.

(5) *Coprolites*

Coprolites are fossil rejectamenta often found in association with the animals which made them. These give an admirable clue to feeding habits. Thus, those of the dolphin-like ichthyosaurs of the Mesozoic are spirally grooved and contain the shells of belemnites, extinct relatives of the modern squid. The spiral character is indicative of the form of the interior of the intestine, while the belemnite shells show that even in their food these old-time reptiles converged in a remarkable way toward the modern dolphins,

which, being mammals, have succeeded to their rôle on the high seas.

The coprolite, associated with the ground sloth *Nothrotherium,* of which mention has been made, has been analyzed with great detail and not only tells us of the food of the sloth, but that the plants of his day, and, therefore, the climate were

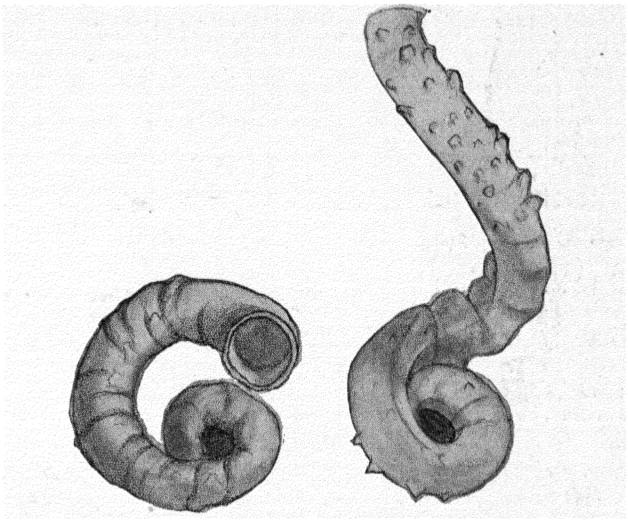


Fig. 11—FOSSIL WORM TUBES (*Spirobus spinuliferous*)

From the Devonian period

essentially as they are at present in New Mexico, and, further, that he died in the *spring* of an unknown year!

Sometimes, as in certain salamander-like forms from the Carboniferous strata of Mazon Creek, Illinois, the intestinal form is clearly outlined in all its windings by the mud that had sifted in before the organs had perished. Again, under this head come worm castings, masses of molded sand which have passed through the worm's intestine and from which the nutrient matter has been digested. These may be seen on a lawn; they also cover certain modern beaches in abundance and are occasionally preserved in some of the most ancient sediments.

(6) *Artificial Structures*

Under this head would come the various implements and other artifacts* made by fossil man and often accompanying

* Artifact, a product of human workmanship, especially of aboriginal man.

his actual remains, although at times they are the only records of his existence in certain regions. In the case of the Dune dwellers in central Mongolia, who have been described by Dr. Roy C. Andrews, no actual bones have ever been found, but since the artifacts correspond with those of the Mousterian culture of Europe, associated with the Neanderthal* man, it is inferred that the Dune dwellers were similar in age and physical characteristics.

Turning to the animal kingdom, we find fossil worm tubes (Fig. 11) formed of the sand, surrounding the burrow, cemented together by slime from the worm's body. Caddis worms build cases of bits of leaves, twigs, sand, or small pebbles, the last two of which may be found as fossils. This is also true of certain Protozoa (rhizopods), which build shells of agglutinated† foreign particles, sand grains and the like, cemented together by the slime from their body.

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* See page 96.

† Agglutinated, held together as if glued.

CHAPTER III

THE NUMBER AND AGE OF FOSSILS

A Census of Fossils

So great a number of fossil species has been described in the literature of paleontology that an attempt to prepare a census would be an extremely difficult task. And one can rest assured that the total number of undiscovered forms would exceed the known ones by a very large majority. Then, too, the criteria of species, as used by various systematists, vary so greatly that almost every revision of a group or given fauna shows results which differ materially from the previously accepted number; the latter is generally reduced owing to synonyms or to disregarding as species the endless variations within a group due to age, sex, or other cause. One must always bear in mind the vicissitudes to which the strata and their contained organisms may be subjected; they may be crushed and folded, or metamorphosed through nearness to volcanic material; the percolation of acidulated waters may dissolve away the fossils within them; and finally the rocks themselves may have suffered erosion to such an extent that thousands of feet have been destroyed. This last vicissitude may be local or may extend over vast areas. These, together with long periods when the lands were worn almost to sea level and, locally at least, no deposition of sediments could occur, constitute the "lost intervals" during which life must have existed, but of which there can obviously be no fossil record.

It has been estimated, although to what degree of accuracy I have no means of telling, that we know perhaps one out of each thousand of the sorts of creatures of the geologic past. Naturally the possibility of discovery grows less as one passes backward to more and more ancient rocks, for the chances of destruction by any of the several agencies we have discussed are increased by time.

Of the number of fossils there can be no possible estimate given, the Yale collection alone containing several hundreds of thousands, and there are vast areas of limestone and bone conglomerate made up almost entirely of organic remains. One of the largest buildings ever erected by man, the great pyramid of Cheops, is built of nummulitic limestone, consisting largely of the tests* of marine Protozoa which lived during Eocene times, the greatest of which is no bigger than a silver quarter (Fig. 12). Imagine if you can their numbers! Animal and plant life teems today wherever conditions of environment permit; so must it have been in the past, for such is the prodigality of living organisms that a region always contains all that the traffic will bear, and there is no reason to believe that it has not been so for hundreds of millions of years.

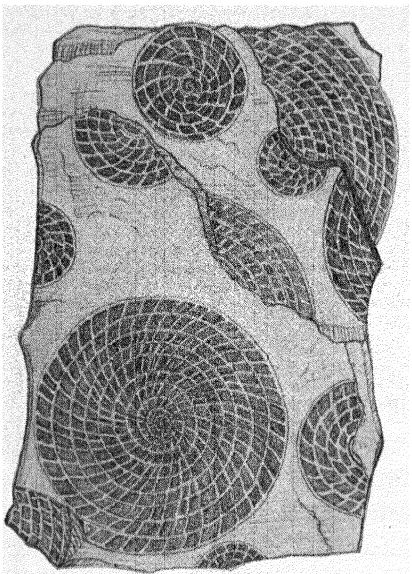

Fig. 12—A PIECE OF NUMMULITIC LIMESTONE

Showing the abundance of small fossils. They are shown here in cross-section. The famous pyramids of Egypt are built of this type of material

(Redrawn from Eastman-Zittel)

It is obvious, therefore, that, with such a profusion of material at its disposal, the science of paleontology, due to the devoted labors of its disciples, has enriched our knowledge of the past life on the earth in no uncertain way. There is still much to do upon the material already collected and in our great museums, some of which is from exhausted localities. What the rocks may yet yield to our successors in the science no man can say—except that the harvest will be rich.

How the Age of Fossils Is Determined

Geologists have been accused of reasoning in a circle on the ground that they determine the age of the fossils from the strata, then the age of the strata from the fossils, and there is

* Tests, the external, hard covering of invertebrate animals.

sufficient truth in the statement to make the criticism the more mischievous. The sequence of the strata must first be determined, which implies, of course, recognition of disconformities or breaks in the deposition, for manifestly the entire geologic column with its thousands of feet of sediments cannot possibly be seen in any one place. Even if the sequence is undisturbed, as in the Grand Canyon, but a portion of the record, from Proterozoic through Paleozoic time, is displayed in this most stupendous section. Generally the lines of demarcation between successive geological horizons or periods are clearly defined and indicated by a difference in the character of the sediments, such as a change from shale to sandstone or conglomerate and often of color. Again, one horizon may pass into another without visible break, but a decided change in the contained fossils will imply a greater or less unrecorded lapse of time.

Having settled the sequence of the strata in a given region, fossils are sought for, especially such genera and species as are sufficiently distinctive to be considered "horizon markers." Once determined, these serve to identify the age and, therefore, correlate the rocks containing them wherever they may be found. Evolution is so orderly a process that not only may one judge the age of a given fossil, for instance that of a horse, but he may even predict in advance of their discovery the horses which should characterize certain intermediate stages and where they may be sought for in the geologic column, and thus upon discovery determine the age of the containing horizon. Predictions such as these have actually been fulfilled in certain striking instances.

The antiquity of fossils may be determined from several criteria: By the known position in the geologic column of the rocks containing them, or, if the particular fossil represents a form new to science, by certain of the associated organisms which have previously been identified. One must, however, guard against the possibility of the intrusion of the specimens into strata of an older age. This is especially likely to occur when one is dealing with anything pertaining to humanity, either his artifacts or his actual bones. Then, too, older strata with their contained fossils may have been eroded and the material redeposited. The sediments are often the result of the dis-

integration of older rocks, their fossils showing the effects of weathering or abrasion by having been rolled in a stream.

Stratigraphical Geology

Strata are often given geographical names, that is, names derived from the place or region where they are typically exposed and where they were first studied and described. Thus, the Upper Triassic beds of the Connecticut Valley, which are equivalent in time to those stretching across New Jersey, Pennsylvania, into Maryland, and farther south, are known as the Newark System, while the Upper Jurassic continental deposits in the West, which have produced so marvelous a display of huge dinosaurs, have been known variously as the Como beds from Como, Wyoming, or the Morrison beds from Morrison, Colorado, while Professor Marsh* spoke of them as the Atlantosaurus beds because of a characteristic fossil, the great dinosaur *Atlantosaurus*. In like manner the strata at the summit of the Cretaceous series have been called Laramie, Lance formation, and Ceratops beds, the last from the horned dinosaurs so characteristic of them. The modern usage among geologists is to give the horizon† the first place name which was applied to it in the geological literature, although the name taken from the dominant fossil has the advantage of being applicable wherever the horizon with its contained organisms may be found, whereas place names often seem far-fetched.

Stratigraphic geology has now risen to the ranks of an exact science, and our modern methods of recording precise horizons with the most minute subdivisions not only renders more detailed and accurate our knowledge of historical geology, but also the evolutionary record of life.

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* Othneil Charles Marsh (1831-1899), Professor of Paleontology, Yale University.

† Horizon, in geology, the deposit of a particular time, usually identified by distinctive fossils.

CHAPTER IV

THE LOCATIONS OF FOSSILS

As WE have seen, a prime condition for fossilization of any organism is adequate burial before extensive disintegration sets in. In general, the best opportunities are afforded where animals are abundant to begin with, and where the depositing of sediments is both rapid and varied.

MARINE FOSSILS

The Continental Shelf

The continental shelf, extending from low-water mark to a variable distance from land, but always to a constant average depth of one hundred fathoms at its outer edge, is formed almost exclusively of the waste of the land. The shelf is continually growing in two directions, shoreward, due to the cutting back of the coast by wave action and tidal scour, and seaward, through the continual carrying out of débris as the waves recede and by the tidal currents. The shelf is widest on an old shore, for obvious reasons, but narrow along a newly arisen coast line. Thus, along the Atlantic coast of North America it is very wide in places, the Nantucket Shoals, the Georges Bank, and the Grand Banks being its seaward extension, while part of the Arctic coast with its great number of islands is also included. On the newly arising Pacific coast, on the other hand, the shelf is very narrow. Life teems in the shallow sea overlying this area, stimulated by light and warmth, the seasonal and diurnal climatic change, the unresting motion of the waters, and the ease of isolation by comparatively small barriers—all of which make for relatively rapid organic change.

In spite of the abundant food, the enormous numbers of organisms produce great competition and a resulting struggle for existence, so that these shallow seas have been called the

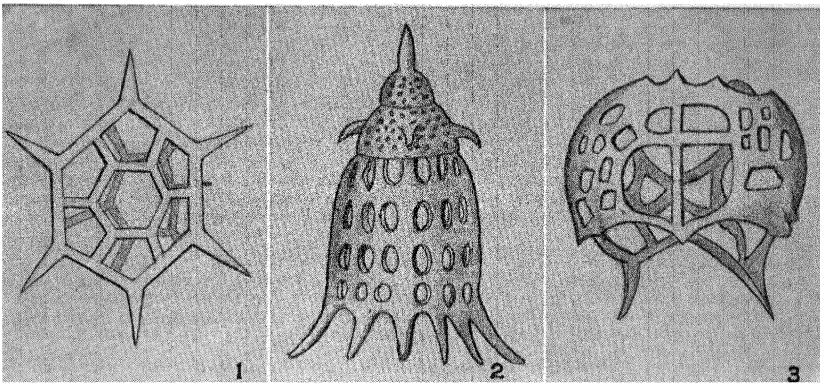
hotbed of evolution. The constant shifting of old material and the addition of new causes the sediments to accumulate rapidly, with a consequent comparatively rich opportunity for burial and fossilization. Thus shallow water marine organisms form the great majority of known fossils.

The strand, that area between high and low-water marks, is less favorable, for strand deposits are trifling beds of sand and gravel and the contained fossils are, as a rule, only such as have hard enough shells to withstand the pounding of the surf. Heavy molluscan shells, more or less broken and abraded, and the bones of stranded whales would meet one's expectations in rocks derived from this source.

Deep-Sea Fossils

On the bottom of the deeper seas the rate of accumulation is almost immeasurably slow, especially in the great deeps, so that although countless organisms have died in the ocean areas, the chances of their fossilization when their remains reach the bottom would not seem to be very great. It is only the more resistant things, such as the teeth of sharks and the ear-bones of whales, that stand much chance of preserval. These are repeatedly dredged from the great deeps where they lie apparently exposed. As a matter of fact, however, we know very little about the deep-sea deposits from actual observation, for only rarely have they been brought up from the deeps by natural agencies and so have come within our scrutiny. Indeed, there are but two localities that have been generally accepted as *bona fide* examples of material formed in the great deeps. These are in Trinidad and Barbados and again in the islands of Timor and Rotti in the Dutch East Indies. In the former region there is a coral formation under which lie 250 to 300 feet of chalky and siliceous earths with clays of various colors and volcanic mud. The siliceous earths are composed largely of the shells of minute Radiolaria and under the microscope appear very like the deep-sea oozes which are obtained by dredging (Fig. 13).

The East Indian beds in Rotti Island contain manganese nodules as well as those of chert (flint), which are full of radiolarian shells in the siliceous limestones and shales, while



Distephus rotundis *Pterocodon campana* *Petalospyris corona*

Fig. 13—A GROUP OF RADIOLARIA

1 and 2, from the Tertiary era of Barbados; 3, from the tripolite of Groth

(*Redrawn from Grabau*)

in the beds in the Island of Timor, in addition to the manganese nodules, there are a great many sharks' teeth and radiolarian remains in the clayey shales. The sharks' teeth are from the genus *Lamna* and are comparable in condition to those dredged from the deep-sea red clays by the British exploration ship *Challenger* and by other expeditions.

In the Island of Celebes, in the Malay Archipelago, there

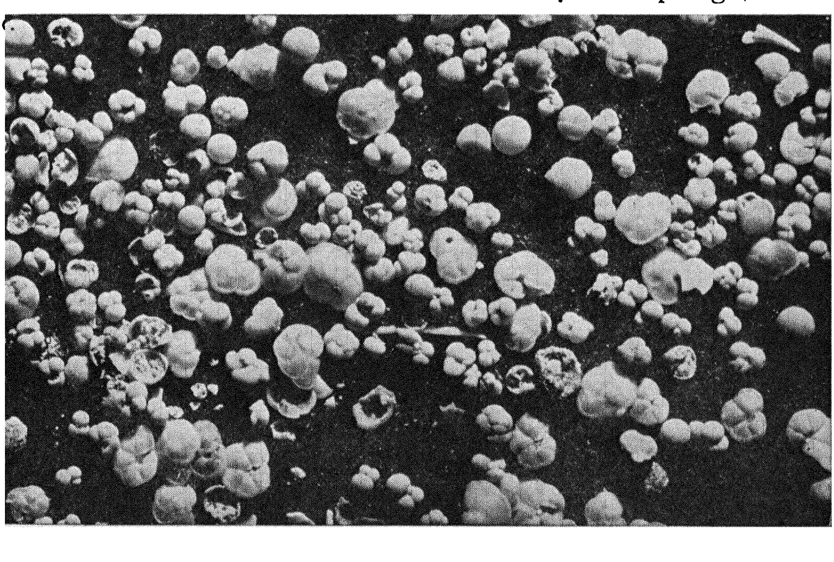


Fig. 14—A PHOTOGRAPH OF SOME GLOBIGERINA OOZE

This tiny animal is important as a limestone builder

are Cretaceous shales containing the organisms known as *Globigerina,* which cover thousands of square miles in the Atlantic and elsewhere today, at an average depth of 1500 to 2500 fathoms (Fig. 14).

Estuarine Deposits

Estuarine brackish-water deposits at the mouths of certain great rivers form more quickly, and here the conditions are much the same as they are on the continental shelf, except that the silting up, save in the actual channels, may be much faster. Here sea and fresh water meet, and the rivers checked in their rapid action, throw down their burden of sediment. The annual expenditure of millions of dollars to maintain harbors and channels at navigable depth points to the rapidity of accumulation.

River Bars and Deltas

River bars with shifting sand banks, even where no estuary exists, are due to the same cause, for flowing water can carry a burden which increases with the square of its velocity. Checking of the river's speed at once reduces its carrying power and the load is deposited in proportion. Some rivers where the amount of sediment is normally great, such as the Mississippi and the Nile, have built out great deltas into the sea. Such deltas when explored for fossils are apt to be highly productive, generally of the remains of land animals and plants or forms of fresh water origin.

There may, however, be occasional marine deposits introduced between those of fresh water origin, due to wave action, or to periods of extremely high water, which sometimes result from a combination of strong on-shore winds and the spring tides which occur at new and full moons. These interpolated beds may contain marine shells. In parts of the Rhone delta, France, marine and fresh water shells alternate; the same is true of the lower deposits of the Po delta in Italy, the upper ones being entirely marine. The deltas of the Ganges in India and of the Zambezi in Africa contain the remains of river animals, turtles, crocodiles, and hippopotami, as well as terrestrial creatures such as antelope, buffalo, lion, and other mammals, victims of drowning brought down by the stream.

Old Inland Sea Bottoms

Certain shallow seas, such as that which covered the vast interior of our continent during Cretaceous time, have left hundreds of feet of marine sediments. Among these a widespread chalk bed is of especial interest, since it has given us a very complete knowledge of fishes, marine reptiles, such as mosasaurs, plesiosaurs, and turtles, flying reptiles or pterodactyls, of which *Pteranodon* with a wing spread of upward of twenty-five feet was Nature's greatest flying creature, and finally the toothed birds, *Hesperornis* and *Ichthyornis*. This, the Niobrara formation, is classically displayed in Gove County, Kansas.

Terrestrial Fossils

Flood-plain Deposits

Of strictly continental deposits, great areas of Cenozoic rocks, with their contained river reptiles and land mammals, are to be found in western United States. These were formerly looked upon as lake deposits, and names such as Bridger Lake and Uinta Lake are frequent in the older literature. But many of the animals were found far out from the assumed shore, sometimes in great abundance. The rate of deposition on a large lake bottom is normally extremely slow and would not account for the thickness of the strata accumulated in a comparatively brief time. So the old idea has been abandoned in favor of a belief that these represent river flood-plain deposits. The law of the carrying power of water obtains here. A river during time of flood is turbid with sediment, but as it overflows its banks, as the Mississippi did during the disastrous floods of 1927 when in places it reached a width of one hundred miles, its rate of flow is checked outside of the main currents of the stream, and the load thrown down. Obviously during such times, casualties to animal life and easy and rapid burial are proportionately accelerated with a comparable increase in resultant fossils. These in turn are rendered accessible by subsequent erosion. Collectively, the flood-plains produced by many contemporaneous rivers would give the impression of lake deposits of vastly greater area but would lack the continuity of the latter, except

where the rivers were confluent. Actual lake deposits must be of comparatively little importance, at any rate from the standpoint of preserving land faunas.

Peat Swamps and Quicksands

Peat swamps and quicksands, although not so extensive as other deposits, have nevertheless preserved some very interesting animals of which we might otherwise know little. It has

Courtesy of the Los Angeles Museum

Fig. 15—PART OF THE GREAT ACCUMULATION OF BONES AT THE RANCHO LA BREA NEAR LOS ANGELES, CALIFORNIA

These animals were victims of an asphalt pool during Pleistocene time

been said that nearly every peat swamp of Pleistocene time in eastern and central United States contains at least one mastodon skeleton, and there have been recorded at least 219 occurrences in the peat swamps of New York State alone.

Quicksands, which at other seasons may be quite innocuous, become terrible traps for the unwary during times of abundant rains or floods. These, as in the case of swamps, bury as they slay, so that the resultant fossils are practically intact. Specific localities will be discussed later.

Coal Swamps

Of course, the widespread, low-lying coal swamps formed during Carboniferous times, with their abundance of plant life, are of the utmost importance. For the coal itself is the consolidated plant material, carbonized and more or less metamorphosed in the different grades of coal, least in the lignite or brown coal, and most in the anthracite. The animal remains are rarer, but we have learned much of the insects, fishes, and amphibians which were denizens of the Carboniferous swamps.

Asphalt Beds

A very remarkable, though unusual, condition for fossilization is found in asphalt, one of the most famous localities being the Rancho la Brea near Los Angeles, California (Fig. 15). The California oils differ from those in the East, for whereas in the latter the ultimate solid residue, after distillation, is paraffin wax, in the former it is asphalt. Here the oil wells up from below through natural pipes and spreads over the ground. The lighter and more volatile products gradually escape, and the remainder becomes more and more viscid, ultimately drying out, especially toward the outer edge of the flow. This becomes covered with wind-blown dust, and hence its real character is concealed. Sometimes, particularly after rains, there may be standing pools of water. A thirsty animal, attracted by water, would venture across the concealed asphalt, and for a while all would be well until he approached the softer portion toward the pipe. Then he would break through, and his efforts to escape, for the asphalt is appallingly sticky, would only render his plight the worse. To this day the death trap is in operation, for every now and then wild and domestic animals and birds are caught and engulfed.

During the Pleistocene period there lived an amazing assemblage of animals in western America, and occasionally a large herbivore—elephant, ground sloth, horse, or camel—would be caught and act as a living bait for wolves, coyotes, sabretooth cats or vultures and other carnivorous birds, who sought to prey upon them. As a rule, carnivores are rare as fossils,

for they usually consist of a comparatively small proportion of the total numbers of any fauna. But here they are largely in

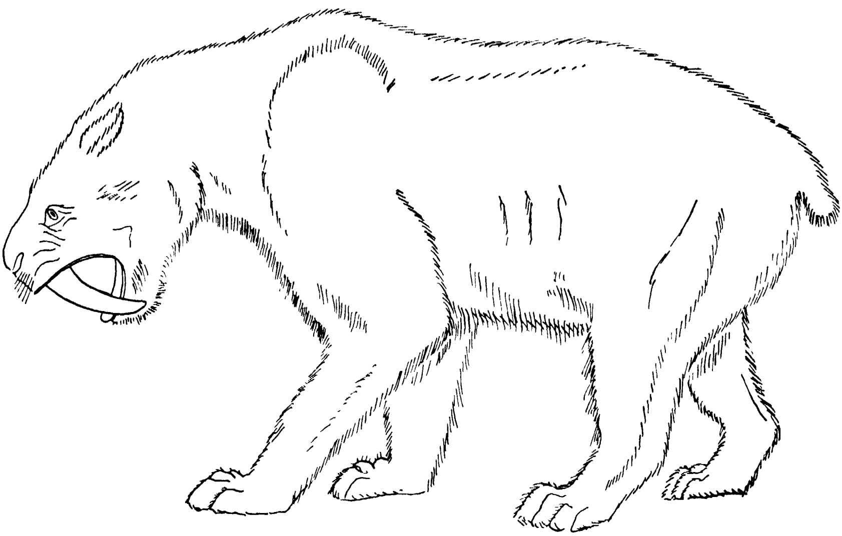


Fig. 16—A RESTORATION OF THE SABRE-TOOTH TIGER, *SMILODON*

Whose skeleton was found in such abundance in the famous asphalt pool at Rancho la Brea, California. This pool formed a natural trap in which various Pleistocene mammals and birds were caught and engulfed

Drawn from the Yale Peabody Museum specimen restored by the author

excess, no fewer than 700 skulls of the sabre-tooth tiger (*Smilodon*) having been recovered (Fig. 16). The asphalt tends to work so that the bones are pulled apart, and one never finds a skeleton in articulation;* but the individual bones are splendidly preserved.

Some Famous Localities of Fossils

Solnhofen, Bavaria

A world renowned locality which has produced fossils, not only in marvelous degree of preservation, but in many instances of unique scientific value, lies in Bavaria. Here the deposits are marine, of Jurassic† age, and in the form of large limestone reefs, the lowermost composed of the remains of sponges, some of great beauty. The later reefs, on the other hand, are formed of calcareous algae‡ (lime secreting sea-weeds) and countless

* Articulation, joined together.
† See chart of "Geologic Chronology," pages 46-47.
‡ See page 13, "The Plant World" in this *Series*.

examples of a large bivalve shell. Between the reefs were lagoons, the floors of which were covered with a fine limy material, the result of wave action on the reefs themselves, which broke off portions and ground them into a fine, gritless mud. These lagoon sediments now constitute the stone used so largely in the art of lithography a generation or so ago. The layers of this lithographic stone average some six inches, the beds being separated by a more clayey material. Animals dying in the lagoons would sink to the bottom where the fine muds would bury them and preserve their remains with wonderful fidelity. The lithographic quarries, especially at Solnhofen and Eichstädt, aside from their commercial output, have greatly enriched our collections and consequently our scientific knowledge of the faunas of the Upper Jurassic time. Obviously, the greater number of the animals were of marine origin and had their being in these seas, but there were land-living creatures as well, which, however, with rare exceptions, were capable of flight, such as dragonflies, pterodactyls or winged reptiles, and true birds, which winged their way over the lagoons in search of prey.

Among marine animals are the impressions of jellyfishes and specimens of Crustacea of various kinds, allies of the existing horseshoe crabs (Fig. 17), squid, and cuttle-fish, some with the sepia still preserved in their sacs, from which during life they could emit a cloud of inky fluid analogous to the smoke screens used by ships during the World War, and finally fishes of many kinds. There were also turtles and crocodile-like forms. Of the flying reptiles, some, like the famous specimen of *Rhamphorhynchus phyllurus* treasured at Yale (Fig. 44), have preserved impressions of the wing membranes with their finest wrinkling, as well as of the rudder-like expansion on the tip of the tail. But per-

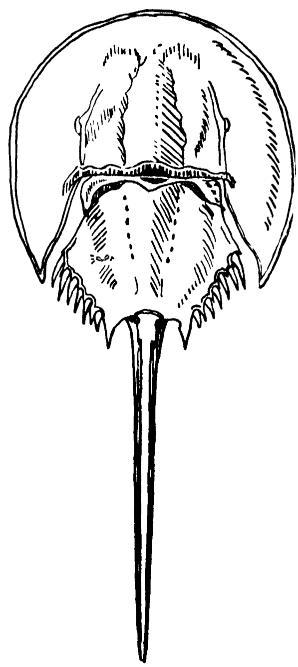


Fig. 17—HORSE-SHOE CRAB, *LIMULUS*

One of the many creatures found in the Jurassic deposits of Solnhofen; their survivors are still common along the seashore

haps the most notable of all is the *Archaeopteryx,* the first bird known to geological history (Fig. 46). Three specimens of this

Fig. 18—A CAST OF *COMPSOGNATHUS LONGIPES,* THE SMALLEST RECORDED DINOSAUR

It was about two and a half feet in length, with the bulk of a domestic cat. It was found in the famous Solnhofen Quarry in Bavaria

From a photograph of a cast in the Yale Peabody Museum

genus have been found, one a single feather discovered in 1860, another a headless bird (1861), now preserved in the British Museum of Natural History, London, while the third, found in 1877 near Eichstädt, practically complete, head, feathers and all, is now in Berlin.

Yet another remarkable find was the smallest known carnivorous dinosaur, *Compsognathus longipes,* about the size of a house cat (Fig. 18). How this creature ever drifted so far from its natural habitat as to be entombed in one of these ancient lagoons one cannot imagine. Of terrestrial vertebrates there are 15 genera and 42 species; of invertebrates and aquatic vertebrates the grand total, except for the insects, is 150 genera and 350 species, of which 88 genera and 175 species are limited to the Solnhofen region and have been discovered in no other locality.

Agate Spring Quarry, Nebraska

This noted locality lies not far from the railroad town of Harrison, in Sioux County, Nebraska. Here, on the south side of the Niobrara River, rise two hills, remnants of a more extensive series of sediments which have been largely worn away. The fossil-bearing horizon is nearly horizontal and extends through both hills. The thickness of the deposit varies from three to twenty inches, the bones toward the bottom being more or less worn and rounded, indicating either longer exposure or farther transportation before they reached their final resting place.

In the larger of the two hills the fossils are in such remarkable profusion in places as to form a veritable pave-

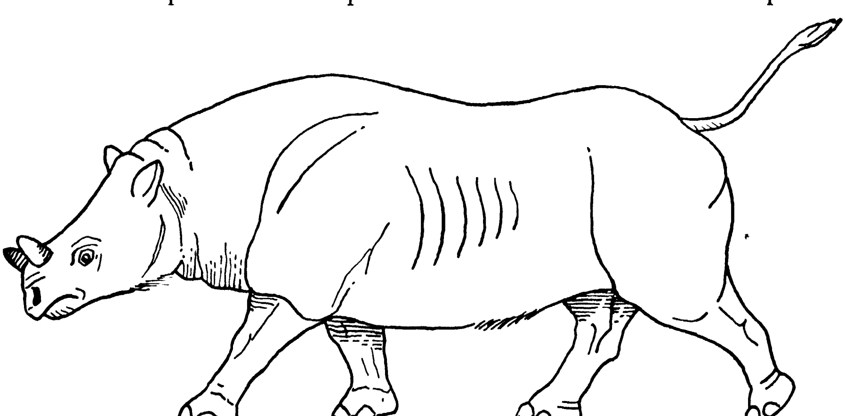


Fig. 19—THE SMALL TWIN-HORNED RHINOCEROS, *DICERATHERIUM*

Whose skeletons were found so abundantly in the Agate Spring Quarry

From a restoration by the author, based upon the skeleton in the Yale Peabody Museum

ment of interlacing bones, very few of which are in their natural articulation with one another.

In order of numbers there is first the small twin-horned rhinoceros, *Diceratherium* (Fig. 19), then the strange clawed ungulate *Moropus* (Fig. 20), of which the American Museum collected seventeen skeletons, complete or nearly so. The rarest animal is one of the giant swine, *Dinohyus* (Fig. 21), a creature with a skull a yard long, and standing six feet at the withers (the highest point between the shoulders).

Some miles farther to the east is another quarry of approximately the same age (Miocene period), which contains remains of the beautiful gazelle camel, *Stenomylus*

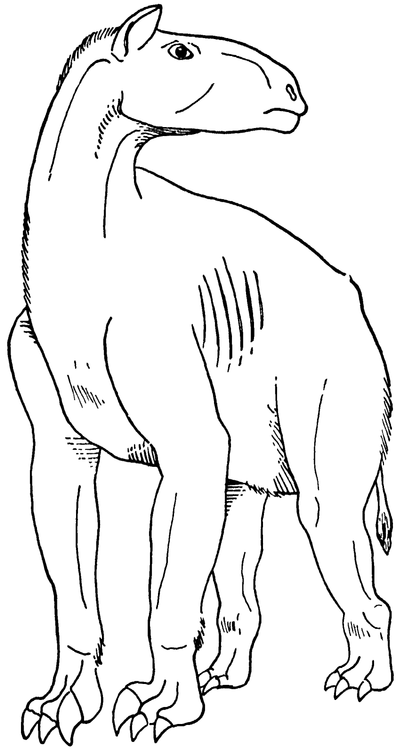


Fig. 20—THE STRANGE CLAWED UNGULATE, *MOROPUS*

Also from the Agate Spring Quarry

From a restoration by the author, based upon the skeletons in the American Museum of Natural History and in the Yale Peabody Museum

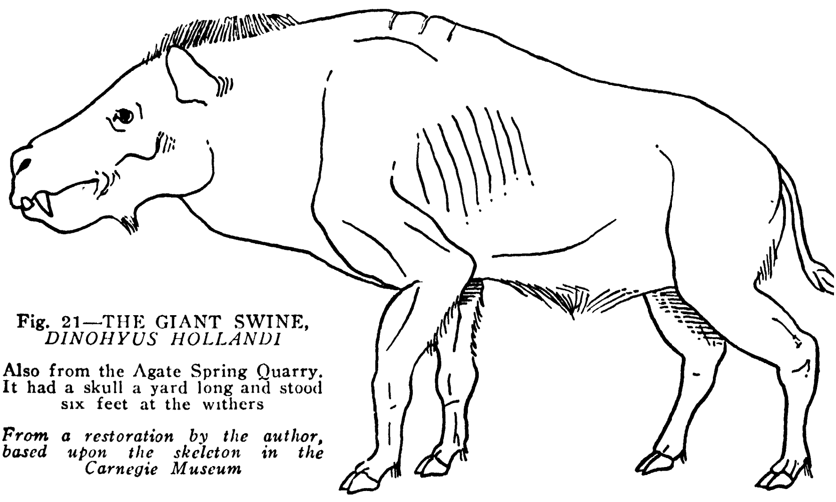


Fig. 21—THE GIANT SWINE, *DINOHYUS HOLLANDI*

Also from the Agate Spring Quarry. It had a skull a yard long and stood six feet at the withers

From a restoration by the author, based upon the skeleton in the Carnegie Museum

(Fig. 22), some of the skeletons completely articulated, others disarticulated. Here, out of half a hundred individuals collected by parties from Amherst College, Yale University, the American Museum, and Carnegie Museum, all pertain to this one species save a single skull of a huge wolf-like carnivore, probably a

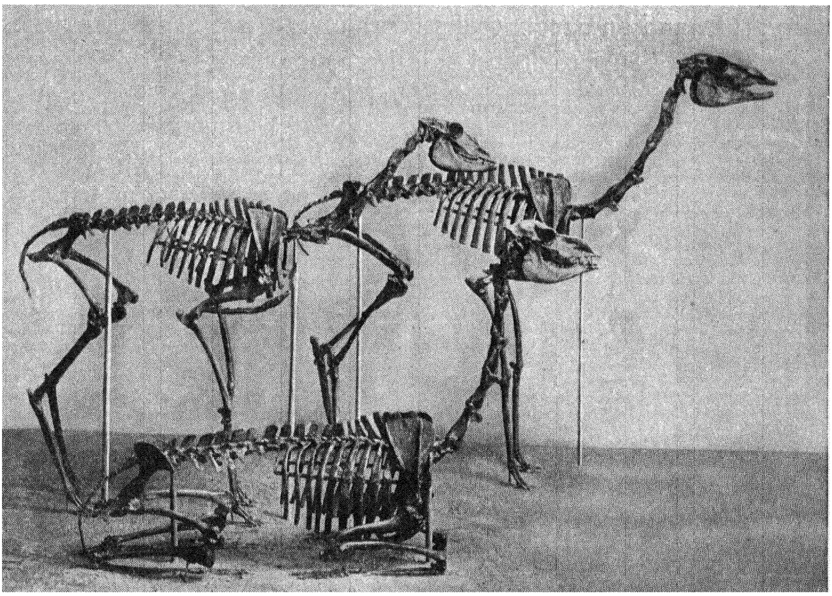


Fig. 22—A GROUP OF GAZELLE CAMELS (*Stenomylus*)

Collected by the author and mounted in Yale Peabody Museum. These skeletons, along with forty others, were found near Agate Spring, Nebraska. Such a profusion of skeletons belonging to the one genus, and the fact that there was only one other associated skeleton, lends to the belief that these were all victims of a common disaster

fellow victim of a common disaster. In both instances the deposits are river sands and seem to represent large coves in the back waters of which the carcasses found lodgment after drifting down stream from the place of catastrophe, wherever that may have been. An alternative view, that of quicksands at the bottom of a pool in which the creatures were engulfed when they came for water, might be held, and the confusion of the bones lends weight to this theory, for the sands shift and move, as did the asphalt mentioned above, and pull the skeletons apart.

It is difficult now to determine the former extent of these deposits, for much natural erosion has occurred, but they were

surely local and exclusive and do not begin to include the total numbers of species which inhabited the region during Miocene times.

The profusion of individuals from the Agate quarries may be judged from a single block now in the American Museum (Fig. 23). This block measures $5\frac{1}{2}$x8 feet, and contains twenty-two skulls and an uncounted number of skeletal bones. As these average 198 bones to an animal, there may be at least 4356 bones in the block of forty-four square feet, or ninety-nine to the square foot.

The Carnegie Museum has excavated in addition 1350 square feet, which have yielded 164,000 bones or 820 skeletons. Based on this yield, the estimate of the number of animals in the entire hill is:

Diceratherium	16,400 skeletons
Moropus	500 skeletons
Dinohyus	100 skeletons

Mount St. Stephen Region, British Columbia

An amazing discovery by Dr. Charles Doolittle Walcott (1850-1927), late secretary of the Smithsonian Institute, on the side of Mount Wapta, British Columbia, disclosed a small area of dark shale on which were impressed as a film of carbon the most delicate parts of fossil animals of lower Cambrian time. These consisted of jellyfish, worms of various sorts, sea-cucumbers, and trilobites, all with appendages, traces of the gut, and other internal structure preserved with the utmost accuracy. These were creatures which lived upward of 500 million years ago, and on top of the sediments which bear them there were laid down several miles of thickness of strata which were solidified into rock and the whole mass elevated by crustal movements into mountain masses and later eroded to form the mountains and canyons.

At the locality where Dr. Walcott found his specimens, subsequent erosion had removed the overlying rocks to the precise level of the older formation, when by fortunate chance the keen eyes of the geologist discerned the impressed organic remains. It is a matter greatly to be wondered at that such fragile organisms should have left any traces whatever, but that they should

be so perfectly preserved and have survived the subsequent vicissitudes to which they have been subjected—the mighty

Courtesy of the American Museum of Natural History

Fig. 23—A SLAB FROM AGATE SPRING QUARRY

The profusion of bones may be judged from this picture of a single block now in the American Museum of Natural History. This block measures 5½ x 8 feet, and contains twenty-two skulls, and an uncounted number of skeletal bones

mountain forces, the crushing weight of the thousands of tons of overlying rock, and the elements which led to its later removal —,as well as the final discovery of the small locality, are a series of happy accidents which seem almost providential. The odds are so immeasurably against such an event that its duplication will probably never occur.

Such revelations, however, lead to a very optimistic hope that, in spite of the present limitations of our knowledge, our successors in paleontological research will one day be able to reveal the continuity of life, in all of its varied ramifications, with a high degree of perfection and detail.

Bone Cabin Quarry, Wyoming

Yet another famous locality is Bone Cabin Quarry, where the author had his initiation into the mysteries of field technique. It lies about twelve miles from Medicine Bow, Wyoming. This is in deposits known as the "Morrison" formation, of Upper Jurassic age. The outcrop consisted of weathered fragments of limb bones and vertebrae of the giant dinosaurs of that time.

These covered the ground in such profusion that a sheep herder used some of them to build the foundations of his hut, hence the picturesque name of the quarry.

The region, now over 6000 feet above the level of the sea,

Fig. 24—BONE CABIN QUARRY IN 1899, WITH THE BONES OF *BRONTOSAURUS* PARTLY EXPOSED

From a photograph by the author

was once low-lying, and the sediments were the accumulations near an ancient shore line or the sloping bank of a muddy estuary or lagoon. Here the dinosaurs must have lived, not far from the place where they lay buried. Rarely does one find an approximately complete skeleton; the remains consist largely of

articulated limbs or tails or possibly the neck which must have been held together by the strong ligaments and tendons after the partial dismemberment of the carcass (Fig. 24). The fragile skulls, on the other hand, are very rare. In the neighboring Como Bluff, however, more complete skeletons have been brought to light, notably the great *Brontosaurus* and the grotesque *Stegosaurus* now mounted in the Yale Museum. Bone Cabin Quarry, after several years of excavation, is by no means exhausted, but, on account of the dip of the strata beneath the surface of the ground, it can no longer be worked profitably except on a large and expensive scale. The American Museum has recovered from it 483 parts of animals weighing in all nearly 100,000 pounds. These represent forty-four large amphibious dinosaurs, three armored dinosaurs, four unarmored bipedal ones, six large and four small carnivores, four crocodiles, and five turtles. Dr. Henry Fairfield Osborn says that this is not one-half the total number, and that in all probability the locality would produce parts of over a hundred giant dinosaurs.

South Joggins, Nova Scotia

In certain horizons of the coal fields of South Joggins, Nova Scotia, tree trunks have been found which are buried in an erect position in the very spot where they once grew. These tree trunks, the largest of which is nine feet tall, as preserved, range in diameter from one to nearly three feet and represent the sturdier among the trees of an ancient forest of Carboniferous* time. They are often well rooted in the ancient soil, and have been preserved by the accumulations of coal and clays above it. They are largely scale trees, *Sigillaria*, which after dying, were broken off, and, the interior having decayed, only the outer rind is now preserved.

They are interesting not only as fossils of that ancient woodland, but even more so from their contents, for the broken summit was for a time at least level with the accumulated soil, the hollow within appearing as a well or pit into which snails and millepedes could crawl, only to die and be buried in the muddy clay that gradually filled the cavity. Yet more remarkable is the fact that these hollows formed veritable death traps for

* See chart of "Geologic Chronology," pages 46-47.

small quadrupedal vertebrates, amphibians belonging to the order Stegocephalia, and others remotely related to the living salamanders. The sediments within the trunks change in character from time to time, indicating that the hollows were a considerable while in filling. In all about fifty-three specimens, including a dozen species, have been recovered from fifteen out of the twenty-five trees which have been catalogued.

ARE FOSSIL REMAINS STILL BEING DISCOVERED?

The amazing success of the American Museum expeditions to Mongolia under the leadership of Dr. Roy Chapman Andrews, emphasizes the fact that the world is not yet fully explored and that vast areas still remain to be systematically searched for fossils. Chinese fossils have been known for years, but as they had, in the eyes of the natives, a high medicinal value, one rarely saw them unless in an apothecary's shop where their scientific significance was entirely ignored.

In fact, the fate of the specimen was ultimate destruction, for a whole rhinoceros tooth would be a hard pill to swallow, but when powdered in a mortar and mixed with other ingredients it would perhaps be no worse to take than many of our modern medicines. This use of fossils, based upon what we are prone to call Chinese superstition, has its parallel in European medieval and later medicinal practice, notably in the use of the unicorn's horn, really the tusk of the narwhal. So high a value was placed on this that a specimen in Dresden was estimated in the sixteenth century to be worth $75,000, and only the very rich could afford its use as a medicament. The artificial value placed upon fossils in China, due to their supposed healing virtues, has retarded the work of science, but it indicated the possibilities of the country, especially of central Mongolia, as a fossil field, an indication which has been abundantly justified.

It was scientifically a virgin country and has given us animals, not only abundant and perfect, but often entirely new to our paleontological lore. The same was true of western United States in the eighteen seventies and eighteen eighties, when not only new species and genera, but unheard of families and orders were continually coming to light. These have greatly enriched our science and especially the collections of our great museums.

The western localities are not now as visibly productive as they were in those days, for the surface indications which were formerly so numerous have largely disappeared through the zeal of many collectors, but undoubtedly the strata are still rich in material which will one day, through erosion, reappear. Certain localities have been entirely exhausted for invertebrate fossils, and the collections made from them have a correspondingly increased value to museums, although the new scientific information which they have revealed has been largely published. It is safe to say that the rocks have by no means yielded all their secrets and that the science of paleontology will continue to flourish for generations to come.

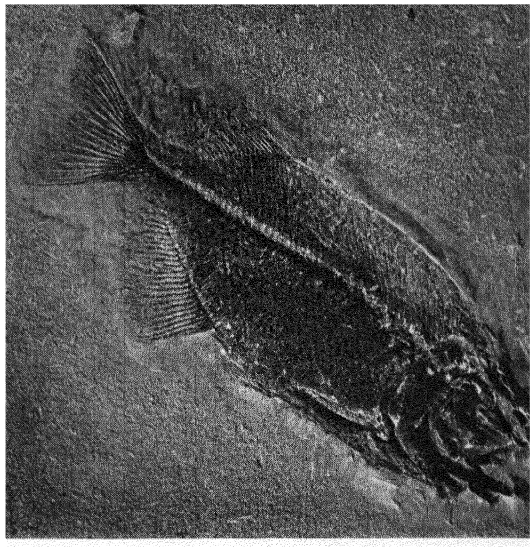


Fig. 25—THE FOSSIL FISH, *PHAREODUS ACUTUS*
An excellent specimen from the Eocene strata of Wyoming
(*After Schuchert*)

The most productive horizons for invertebrate fossils are the shoal water sedimentary rocks, and these may be found everywhere along the sea cliffs, in railroad and other cuttings, along the Niagara Gorge, the Grand Canyon, or wherever these rocks are exposed. Marine vertebrates may also be found under like conditions, but for terrestrial vertebrates, preserved in the continental deposits, the greatest opportunities lie in the semi-arid parts of the earth, in western United States, the Patagonian pampas, the Faiyum desert of Egypt, South Africa, central Asia, and, as a likely though unexplored area, central Australia. In such areas as these there is little vegetation to obscure the geology and in nearly every case there has been extensive erosion due to the occasional torrential rains and the lack of a protective mantle. In the more

humid regions the overlying soil—six feet or more in New England, sixty feet in Brazil—not only covers up the actual strata but is largely the result of the disintegration of the rocks themselves together with their contained fossils. The explorations in Mongolia, to which we have already alluded, have merely scratched the surface along certain narrow lines of march. But even so, the results have been remarkably rich. A widespread intensive survey conducted by many parties over the entire area would produce returns which cannot be estimated and much of which would be new to science. For species are often extremely local in their geographic distribution, and the reconnoissance work already done may well have passed by the haunts of curious and unusual bygone forms.

CHAPTER V

FOSSILS AND THE THEORY OF EVOLUTION

SINCE all animate nature represents a single great evolutionary process—and that is the only logical explanation which can be offered for its existence—it is evident that the true story of the continuity of life can only be displayed in its entirety by combining in one series all the evidences of animal life, whatever their age. The existing forms alone would not serve, for while Nature has preserved alive representatives of the most archaic as well as of the most recently evolved organisms, there are extremely important groups—graptolites, trilobites, ammonoids, as well as a marvelous array of vertebrates, stegocephalians, dinosaurs, and others, which have been entirely blotted out and have left no descendants in the living fauna of the globe. On the other hand, many existing creatures, some of which have no hard parts, such as the naked protozoan, *Ameba,* and which we assume to be ancient because of their simplicity of organization, are practically impossible of fossilization and, therefore, are unrepresented in the paleontologic series. It is only by an inclusive arrangement that a right conception of animate nature becomes possible, if one would view the evolutionary process as a whole.

It is evident, therefore, that the fossils reveal to the systematist and evolutionist much that existing nature cannot show. Who, viewing the lordly elephant with its ponderous bulk carried on four massive limbs, its distinctive proboscis and tusks, would see in it any community of origin with a Florida manatee with its fish-like form, split prehensile lips, propelling tail, flipper-like fore limbs, and no hind limbs at all? And yet the Faiyum region of Egypt has revealed fossils, clearly the ancestors of both elephant and manatee, the skulls of which are so alike that in some instances, notably that of *Moeritherium,* the highest authorities were for a while of divided opinion as to which group

it belonged, the proboscidean or sirenian. Thus paleontology aids the systematist in his search for relationships which the modern animals could not possibly reveal.

The three main lines of evidence for the evolution of any group of animals are *comparative anatomy, ontogeny,* and *phylogeny.* In the first one studies structure and form, distinguishing between what are called homologous organs. Such are the fore limbs of vertebrates, and distinction is made between them as to whether they are grasping organs like our own, running organs as in the horse, paddles for swimming as in the whales, or wings as in the bird. The basic structure is the same in all, but variety of use has produced dissimilarity of form. A comparative study will at once reveal how in each instance the ultimate adaptation to its peculiar function has been brought about. But no one would attempt a structural comparison of the wing of a bird and that of a butterfly, although their use is precisely the same. They are analogous organs—in their similarity of function—but are in no sense homologous, implying a correspondence in origin, for the wing of the bird is a modified fore limb, whereas that of the butterfly is an outpushing of the body wall which has become greatly expanded, movably articulated, and endowed with muscles. One could not by any stretch of the imagination derive the one wing from the other, nor does the possession of the common property of flight indicate the slightest trace of relationship between their possessors.

Ontogeny is the life history of the individual, from the beginning of its life as an independent cell, derived from its parents' substance, to its death, or, in the case of the potentially immortal one-celled organisms which pass all of their body substance as well as their life to the offspring, it ends with their loss of individuality. Man starts as do other organisms, as a single cell, which, through cleavage, develops into a multicellular being the parts of which are at first all alike. Later there occurs differentiation in form and function by means of a physiological division of labor, the embryo passing through (1) a stage in which segmentation appears and a backbone is indicated, (2) a fish-like stage with gill-clefts in the neck, (3) a stage like an amphibian, (4) others like a primitive reptile, a generalized mammal, and a primate, respectively; finally there appears a miniature man.

All of these marvelous changes, wrought in the first few weeks of prenatal life, are thought to parallel roughly the actual evolutionary changes through which man's ancestors passed during a period of hundreds of millions of years of geologic time. The celebrated German savant, Ernst Haeckel, first formulated what is known as the Biogenetic Law* based upon this principle, although apparently he was not the first to conceive it. It has not universal acceptance among scientific workers today, yet few will deny that individual life-history is one of the proofs of evolution even though, because of the vicissitudes of individual existence and the consequent need of meeting new conditions during the process of growth, a precise parallel between ontogeny and racial history is hardly to be expected.

The third proof of evolution lies in the actual documentary evidences of racial history, or *phylogeny,* as it is called. Rarely can these be obtained among existing organisms, although some phyletic lines in which change is going on rapidly enough for human observation are actually on record. The wonderful modifications which man has wrought in domestic animals and plants through selective breeding are of a comparable sort, and, though largely the outcome of artificial conditions, yet Nature as well as man has had a hand in their production. At all events they show the wonderful plasticity of living beings, and if in the hands of man, why not in the hands of a vastly more powerful Nature? At any rate man's methods are analogous to the process of natural selection and were of the utmost importance to Darwin in the understanding and definition of natural selection itself.

Evolution is, as a rule, an extremely deliberate process; Nature has all she needs of time and circumstance for its fruition, and as a rule the brief time allotted to the individual for his observation is all too little for the purpose. It lies, therefore, within the scope of one whose backward vision has certain elements of immortality to gain a full conception of the phylogenetic process. For not only can such a one visualize past conditions of land and sea, of climate and the various phenomena

* Haeckel's Biogenetic Law may be stated as follows: The life history of the individual (ontogeny) gives a brief résumé of the evolutionary history of the race (phylogeny).

of the physical environment, but he can also see the march of organisms through time. For the last his documents are the fossils. Thus they occupy a position in science held by no other group of phenomena, for they provide the final proof of the process of evolution, and there is no other explanation which can possibly account for them.

Paleontology is, therefore, the final court of appeal to test the truth or falsity of the growing belief in evolution. All that is necessary is as adequate a series of fossils as possible for the determination of their sequence, and the correct interpretation of what they represent, for their teaching is one that cannot intelligently be gainsaid.

CHAPTER VI

PLANTS AND ANIMALS OF THE PAST

EVEN a brief description of the evolution of the entire animal kingdom as set forth in the fossil records would fill many times the allotted pages of this book. One must, therefore, after a general summary, turn to certain groups wherein the fossil series is remarkably complete, referring the reader to more extended works for further instances and greater detail.

THE PALEOZOIC ERA

The Cambrian Period

The earliest evidences of life are extremely meager, masses of limestone and graphite and very few obscure fossils are all we have as evidence, either direct or indirect, of life during the first two eras,* the Archeozoic and Proterozoic, which together constitute over one-half of geologic time as recorded in the sedimentary rocks of our earth. With the ushering in of the Paleozoic era, in its initial period, the Cambrian, the lime-secreting habit is acquired, and now for the first time there are clearly understandable fossils. They represent, however, all of the great invertebrate phyla† whose evolution is thus implied, even though unrecorded, in the preceding eras. Cambrian animals are all marine, showing that the seas were their initial home and that presumably fresh waters, and certainly the lands, were yet tenantless.

These old forms included sponges, corals, worms, trilobites, and the like (Figs. 11, 26, and 27). As yet there is no trace of backboned animals. Vertebrates may well have had their origin during Cambrian time, but it will require "lucky" accidents of preserval and discovery, such as in the Mount St. Stephen

* See chart of "Geologic Chronology," pages 46-47.
† Phylum, plural, phyla), a limb; see page 42, "The Coming and Evolution of Life," in this *Series*.

GEOLOGIC CHRONOLOGY*

(Adapted from Lull, *Organic Evolution*)

ERAS	*PERIODS AND EPOCHS*	*ADVANCES IN LIFE*	*DOMINANT LIFE*
PSYCHOZOIC	Recent (Post-Glacial)	Era of Mental Life	Man
		CASCADIAN REVOLUTION	
CENOZOIC Modern Life 4%	Pleistocene (Glacial Period)	Extinction of Great Mammals	Mammals
	Pliocene	Origin of Man	
	Miocene	Culmination of Mammals	
	Oligocene	Rise of Higher Mammals	
	Eocene	Extinction of Archaic Mammals	
	Paleocene	Rise of Archaic Mammals	
		LARAMIDE REVOLUTION	
MESOZOIC Medieval Life 11%	Cretaceous	Extinction of Great Reptiles Specialization of Great Reptiles Rise of Flowering Plants	Reptiles
	Jurassic	Rise of Birds and Giant Dinosaurs	
	Triassic	Rise of Dinosaurs	

<table>
<tr><td colspan="4">APPALACHIAN REVOLUTION</td></tr>
<tr><td rowspan="6">PALEOZOIC
Ancient Life
30%</td><td>Permian
(Glacial Period)</td><td>Extinction of Much Ancient Life</td><td rowspan="2">Amphibians</td></tr>
<tr><td>Carboniferous</td><td>Rise of Primitive Reptiles and Insects</td></tr>
<tr><td>Devonian</td><td>Rise of Amphibians
First known Land Floras</td><td rowspan="2">Fishes</td></tr>
<tr><td>Silurian</td><td>Rise of Lung-Fishes
First Air-breathers (Scorpions)</td></tr>
<tr><td>Ordovician</td><td>Rise of Land Plants and Corals
Rise of Armored Fishes</td><td rowspan="2">Higher
(shelled)
Invertebrates</td></tr>
<tr><td>Cambrian</td><td>Rise of Shelled Animals
First known Marine Faunas</td></tr>
<tr><td colspan="4">GRAND CANYON REVOLUTION</td></tr>
<tr><td>PROTEROZOIC
25%</td><td></td><td rowspan="2">Evidences of Life Very Scanty</td><td>Shell-less
Invertebrates</td></tr>
<tr><td>ARCHEOZOIC
30%</td><td></td><td>Unicellular
Animals and Plants</td></tr>
<tr><td colspan="4">COSMIC HISTORY</td></tr>
</table>

* See Chart of Geologic Time in "The Earth" in this *Series*.

Quarry, to disclose them, because of their probable soft-bodied character.

The dominant life of the Cambrian, by which we mean not necessarily the highest in the evolutionary sense, but the forms which by their profusion and power seem to have the ruling position, were doubtless the trilobites (Fig. 27). These crustaceans are remotely related to the shrimps, the lobsters, and the crabs of today. They had a resistant upper shell covering head and body but apparently a soft lower surface and appendages, for the latter are rarely preserved. They were generally crawling forms, inhabitants of the sea bottom, but probably had the power of swimming in a somewhat jerky way. Some groveled in the mud for food, others were more actively predacious, and, although most of them had well developed eyes, a few were blind as though they dwelt below the limit of sunlight, or more probably, were nocturnal in habit, since most of their remains come from shallow water deposits.

Courtesy of Dr. Carl Dunbar

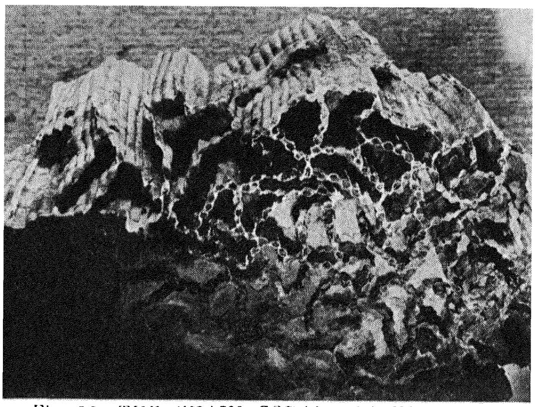


Fig. 26—THE CHAIN CORAL, *HALYSITES*

Characteristic of the Silurian era; an example of a pseudomorph in which the original lining material has been replaced by silica

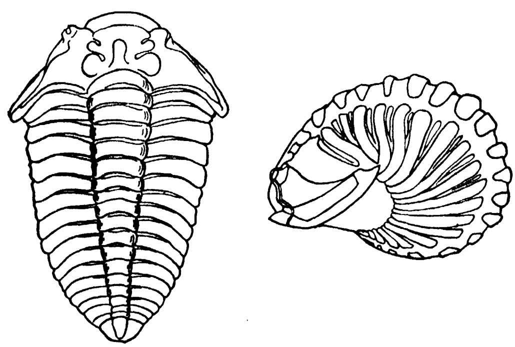


Fig. 27—TRILOBITES (*natural size*)

They formed the dominant life of the Cambrian period. They were generally crawling forms, inhabitants of the sea bottom, but probably had the power of swimming. By Upper Cambrian time they had developed the habit of coiling up for defense

From specimens in the Yale Peabody Museum

By Upper Cambrian time the trilobites had developed the

habit of coiling up for defense, after the manner of armadillos. In size the trilobites ranged from a fraction of an inch to 27½ inches. Trilobites are ancestral, either directly or indirectly, to all other arthropods—crustaceans, scorpions, spiders, millepedes, and even the insects. The Cambrian has been known as the Age of Trilobites.

The Ordovician Period

In Ordovician time, land plants probably arose, having their origin in certain marine algae which gradually crossed the strand, becoming more and more inured to an air instead of an aquatic environment. Perhaps the most characteristic single group of marine fossils of the Ordovician are the graptolites, so called from their resemblance to some sort of writing on stone.* These were colonial organisms belonging to the coelenterate phylum which includes also the polyps and jellyfishes and is therefore low in the scale of invertebrate life. Of the graptolites, the actual polyps are not preserved, but

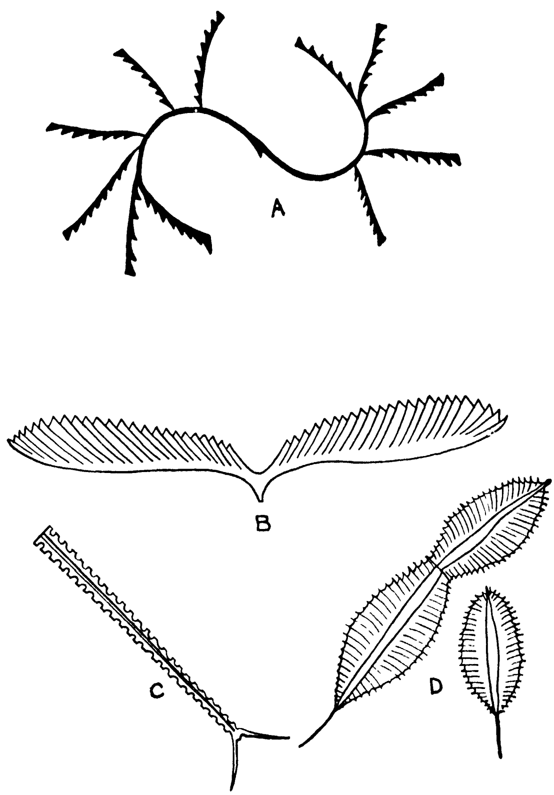


Fig. 28—GRAPTOLITES

The most characteristic group of marine fossils of the Ordovician period. These were colonial organisms belonging to the same phylum as the polyps and jellyfish. The actual polyps are not preserved, but their horny sheaths have been carbonized and impressed upon the rocks. *a, Coenograptus gracilis; b, Didymograptus pennatulus; c, Climacograptus bicornis; d, Phyllograptus typus*

(*Redrawn after Hall*)

* Graptolite is from two Greek words, *graptos,* written, and *lithos,* stone.

their horny sheaths have been carbonized and impressed upon the rocks. Sometimes they are like miniature saw blades with teeth on one or both sides; again they are leaf-like and may be single or branched, the latter sometimes giving rise to dendritic or tree-like colonies. The polyps were situated in the little tooth-like notches. The animals may have been fixed to the sea bottom as are their modern relatives, or attached to floating material, or even provided with devices of their own to render them buoyant. They were at the mercy of the waves or currents of the sea, since they had no recognizable powers of locomotion. (See Figure 28.)

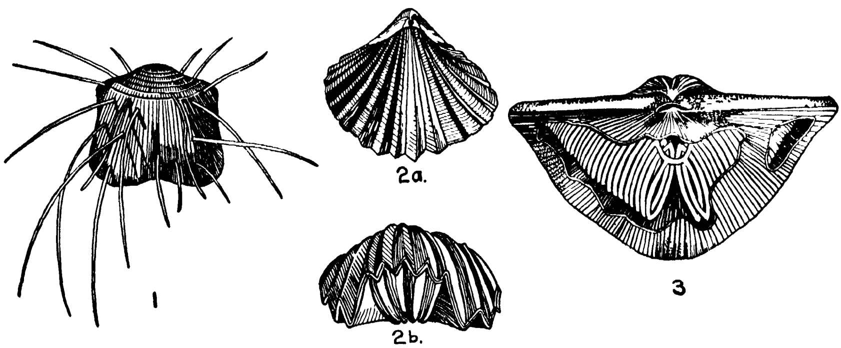


Fig. 29—A GROUP OF BRACHIOPODS

1, *Productus longispinus;* 2a and 2b, *Rhynchonella quadriplicata;* 3, *Spirifer striatus,* with part of the shell broken off to show the inner spiral supports

(*After Grabau*)

Trilobites were still existing in great variety, both of numbers and of kinds, and there was a host of shelled invertebrates —molluscs, and brachiopods or lamp shells (Fig. 29), as well as corals.

Indubitable remains of armored, fish-like creatures have also been found which show that the vertebrates had already developed, for these specialized fish are lateral offshoots from the main line of vertebrate evolution.

The Silurian Period

The Silurian period gives us the first record of air-breathing animals. Land plants had already been established, as plants are necessarily the forerunners of the animals in any environment, for no animals have the power of constructive chemistry

which would enable them to utilize products of the mineral realm directly as food. They must, in the long run, avail themselves of the green or chlorophyll-bearing plants which do possess such ability. The first air-breathing animals of which we have any actual evidence are the scorpions (Fig. 30), which, in spite of their age, are much like those of today. As they were carnivorous and, therefore, did not eat plant food, their presence implies also that of creatures which did and which in turn formed their prey. For doubtless there was then, as now, an ever-widening web of interdependence in organic life.

The fishes of the Silurian period are all in fresh water sediments. We have reason to believe that vertebrates had their origin and initial evolution in running, fresh water. This alone would give the impetus apparently necessary to produce the peculiar mode of progression—by lateral wriggling—which in turn gave rise to segmental muscles and an axial stiffening, the notochord. The latter was later replaced in higher groups by the vertebral column. Vertebrates seemingly did not invade the seas until late Devonian times; the most plausible reason seems to have been the menace of the molluscs, until then the ruling denizens of the deep in point of prowess.

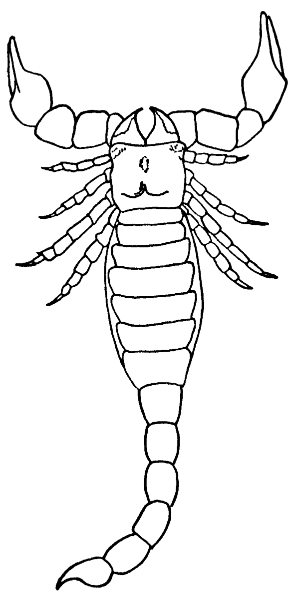


Fig. 30—THE SCORPION, *PALAEOPHONUS NUNCIUS*

Scorpions are the first air-breathing animals of which there is any actual evidence, and in spite of their age are much like those of today

(After Pirsson and Schuchert)

The Devonian Period

The march of evolution progressed markedly. Devonian time has been called the Age of Fishes because they were the dominant forms of life. Not only are they numerous and well preserved, especially in the series of fresh water and estuarine rocks known as the Old Red Sandstone,* but they had already

* Old Red Sandstone, a thick series of broken rocks, mostly sandstone, red in color, belonging to the Devonian period and found in Great Britain and northwestern Europe.

differentiated into several distinct orders, such as the sharks, the ancient armored fishes known as ostracoderms and arthrodires, and the ganoid fishes and dipnoans. The last two groups together with the sharks have left modern descendants, although of ganoids and dipnoans there are but few survivors.

These modern relics aid us in the reconstruction of the manner of life of those of Devonian times. All are fresh water in habitat and have, though in varying degree, the power of utilizing atmospheric oxygen in time of scarcity of available oxygen in the water. The Devonian period was a time of marked aridity of climate, during which the streams would periodically cease to flow with resultant stagnation of the fresh water remnants which were left. This would place a premium upon powers of endurance, and especially on air-breathing as opposed to water-breathing. For a while these fishes could still carry on, especially if they could pass the worst of the droughts in the condition of torpor known as estivation. But with progressive aridity, extending such periods over too great a proportion of the creature's life and leaving insufficient time for the normal activity of its existence, the problem had to be met in another way—by actual emergence and the assumption of a terrestrial mode of life. This, aside from the origin of life itself and that of the vertebrate type out of some unknown worm-like ancestor, was perhaps the most momentous occurrence in all evolution. For it made possible the reptile, bird, and mammal including man himself, and without it the fishes would be to this day the highest expression of vertebrate progress.

The Devonian period saw not only the assumption of lung-breathing on the part of certain fishes, but it also gave us in a single archaic footprint (Fig. 9) the first tangible record of a terrestrial backboned animal. Thus did our humble ancestor leave behind him "footprints on the sands of time."

The conquest of the lands is first attained by the invertebrates —the scorpions, shellfish, worms, and thousand-legs. But these are lowly folk and will never effectually dispute this new realm with the vertebrates to come.

Devonian seas were replete with invertebrates—corals, brachiopods, trilobites, and molluscs, of much the same character as were those of the Silurian period, and not until its close did the

fishes invade the marine realm, as others of their descendants invaded the terrestrial. It was a time prophetic of the rôles the backboned animals were yet to play.

The Carboniferous Period

The Carboniferous period which followed was also marked by great events in organic advancement. In Lower Carboniferous time the seas claim our interest, for the invertebrates are developing remarkable types, especially among the sea-lilies or crinoids (Fig. 31), the echinoids or sea-urchins, and the peculiar screw-like colonial organisms (bryozoans) known as *Archimedes,* from the philosopher of old (Fig. 32). There was also a great revival of sharks, which, in spite of their antiquity, now become dominant marine forms.

The Upper Carboniferous period shows alternations of land and sea conditions, marine strata interspersed with those bearing beds of coal—the product of the abundant vegetation of low-lying fresh-water swamps. These beds are our most

Courtesy of Dr. Carl Dunbar

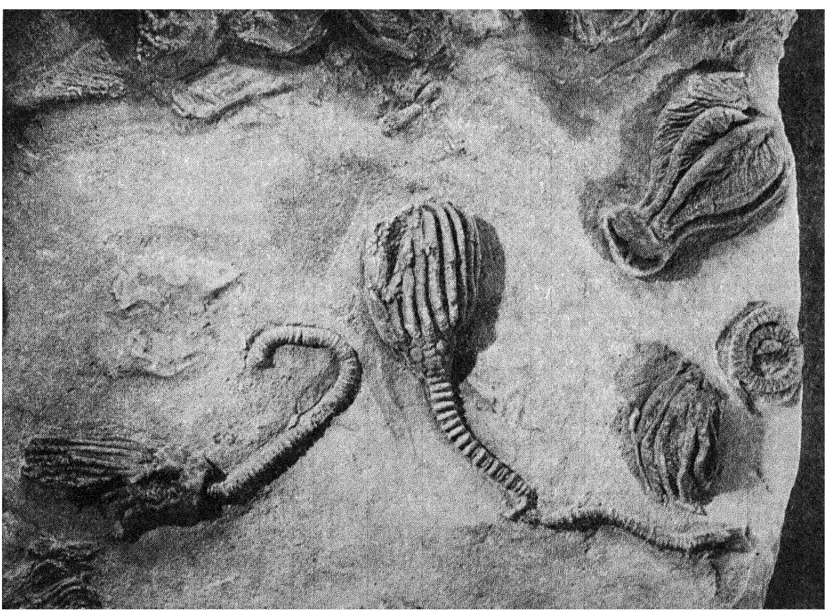


Fig. 31—CRINOIDS or SEA-LILIES

Characteristic of the Lower Carboniferous period. The food is gathered by these pinnule-bearing arms from the sea-water and conveyed along a median groove to the mouth

productive coal measures* and the debt of modern civilization to them is immeasurable.

In the meantime, not only have the first land vertebrates, the

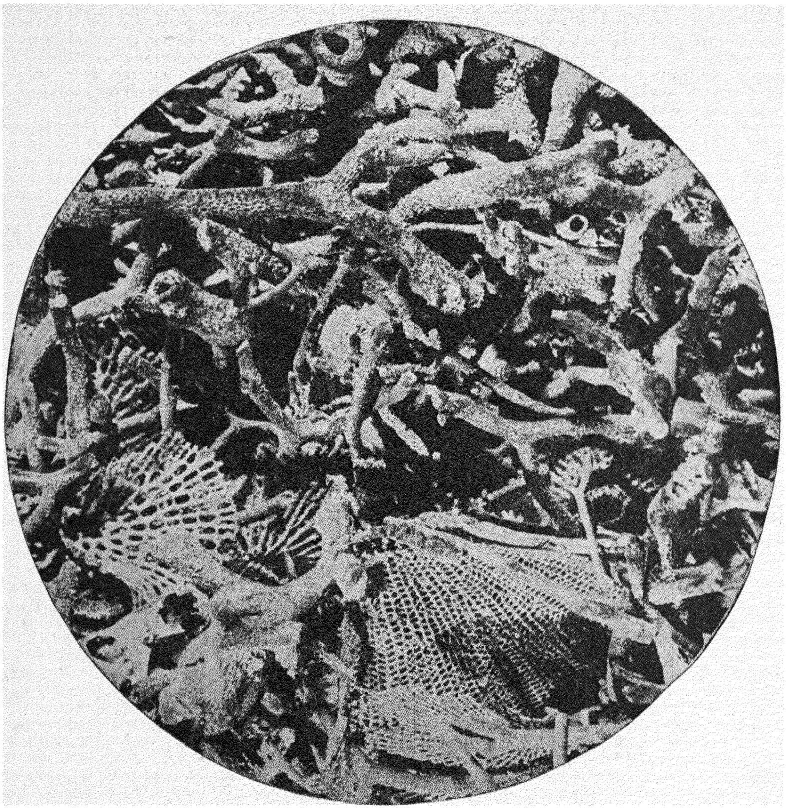


Fig. 32—A TANGLE OF FOSSIL BRYOZOANS

From the Helderbergian formation in Herkimer County, New York. These are colonial polyps which secrete calcareous material around their bodies. They may be attached to sea-weeds or rocks or may grow as free, fan-like expansions, or independent masses of crowded calcareous tubes

Courtesy of Dr. Carl Dunbar

stegocephalians (Fig. 33), established themselves, but actual reptiles have arisen, from which are to come, in turn, the "Rulers of the Mesozoic era." The chief distinction between the stegocephalians, which were amphibians, and the reptiles lies in the youthful stages—the egg and adolescent; the former lay their eggs in the water, and for a while their young are gill-breathers, reminiscent of their piscine ancestors. It is only as adults that

* Measure, geologically, beds.

they become truly lung-breathing terrestrial forms. With the reptiles, on the other hand, the eggs are laid on land, and the young are miniatures of their parents in all respects, gill-breathing being lost forever. It is possible that aridity in late Carboniferous time forced the abandonment of the amphibious life, though not on the part of all, for the stegocephalians endured into Triassic

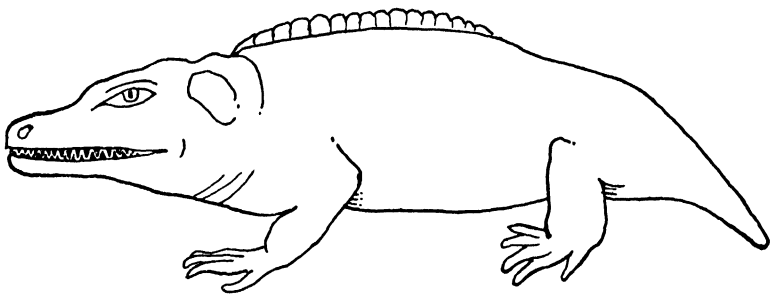


Fig. 33—A STEGOCEPHALIAN, *CACOPS ASPIDEPHORUS*

One of the first land vertebrates

(*Restoration after Abel*)

time and the salamanders and frogs have existed until this day, but on the part of those which by reason of environmental conditions were destined to higher things. The amphibian stage in evolution was merely *en passant,* for amphibians were never dominant forms of life.

Yet another conquest was to occur during the Carboniferous period, namely, that of the air, not by vertebrates this time but by the invertebrates. For out of an humble trilobite ancestry, through some obscure evolutionary line, the insects were to arise and wing their way through the gloomy forests of the coal swamps—roaches, dragonflies, and archaic orders which, as such, have ceased to be. Invertebrate air-mindedness preceded that of the vertebrates by millions of years, for the latter did not essay flight until the Triassic period.

The Permian Period

Rocks of the Permian period reveal climatic stress; gone are the steaming tropical forests, and aridity and glacial cold mark the period. Climatic influence on organic life is marked; insects are few of record, and their enforced periods of hibernation seem

to have given rise to the remarkable change from the *gradual* metamorphosis of their ancestors to the *abrupt* one of the higher orders, as seen in the beetles, butterflies, bees, flies—the great reorganization from grub to winged adult occurring during their quiescent period instead of extending throughout much of their active life, as in the roaches, grasshopper, dragonflies, and bugs. Out of the Permian the higher orders emerge.

Whether or not the glacial cold of Permian time was contributory to the establishment of warm blood in the ancestors of birds and mammals remains to be proven, for the first recorded mammals belong to Triassic time, and the first birds to Jurassic. The inference, however, seems plausible that in some way aridity, which makes for speed and higher metabolism, and cold which places a premium on maintained internal heat and thus prolongs the active period of an animal's life in inclement climates, are responsible. Both aridity and glacial cold were characteristic of Permian times.

With the appearance of insects, the invertebrate evolution is complete, except for minor details of adaptation and structure. And while the Permian period, which closes the great Paleozoic era, saw also the extinction of important groups, notably the trilobites, there has been no new invertebrate type established since.

The vertebrates and higher flowering plants are to hold our future interest.

The Mesozoic Era

The Mesozoic era, which endured for 150 million years, has been called the Age of Reptiles, for although the two higher classes, the birds and mammals, both arose during the era, they occupied subordinate rôles, while all the niches in the economy of nature, including the lands, seas, and air, were occupied by the reptilian hordes. These ranged amazingly in size, from minute nervous forms to the mightiest terrestrial brutes the world has ever seen, and in their habits and adaptations, and hence in their form and structure met every known condition of life save that of the deep sea.

A conservative classification divides the reptiles into at least eighteen orders, with suborders, families, genera, and species

almost beyond reckoning. Of certain of these orders but few examples have come to light, and these are from Africa and from southwestern United States; yet other orders are known from abundant specimens often of such degree of perfection that our knowledge of their anatomy and inferred manner of life renders them fully as familiar to the paleontologist as are many of the existing animals of today.

The Triassic Period

Triassic time is ushered in by widespread aridity which seems to have given the initial trend to the evolution of many reptilian groups, notably the dinosaurs, for the first of these, both plant and animal feeders, are bipedal in gait as though impelled to speed as a prime necessity of existence. They early fall into two groups; probably they always were a divided race whose only bond of relationship lay in their derivation from a common ancestry.

The carnivorous dinosaurs arose as the earlier of the two orders, having their recorded origin near the beginning of the Triassic period, whereas the herbivorous order does not appear till toward the close of the period. In both groups the main evolutionary lines, while differing in certain diagnostic features of skull, dentition, and pelvis, were, nevertheless, because of their comparable gaits and sizes, closely parallel throughout their entire course. There were aberrant* lines in both orders which, because of weight of body, armor, or armament, forsook the bipedal gait and descended once more to the quadrupedal pose of their ancestors. Some of these, especially toward the close of their career, attained a grotesqueness which made them fearsome animals, as were others because of their size or their terrible weapons—teeth and claws—or both.

Dinosaurs are first recorded from the Lower Triassic rocks of Germany; but they soon spread to the uttermost parts of the earth, from Europe to central Asia, southern and eastern Africa, India, and Australia in the Old World, and from the Atlantic coast to the Rockies and British Columbia or to Patagonia, in the New. At first they dwelt in the drier areas, one of the most famous of which was the Connecticut Valley in New England,

* Aberrant, deviating from the ordinary type.

where their footprints are countless although their bones are few. From the Jurassic period on, their known habitat seems to have been low-lying coastal lands, rich in heat and moisture, much of which took the form of swamp and la-

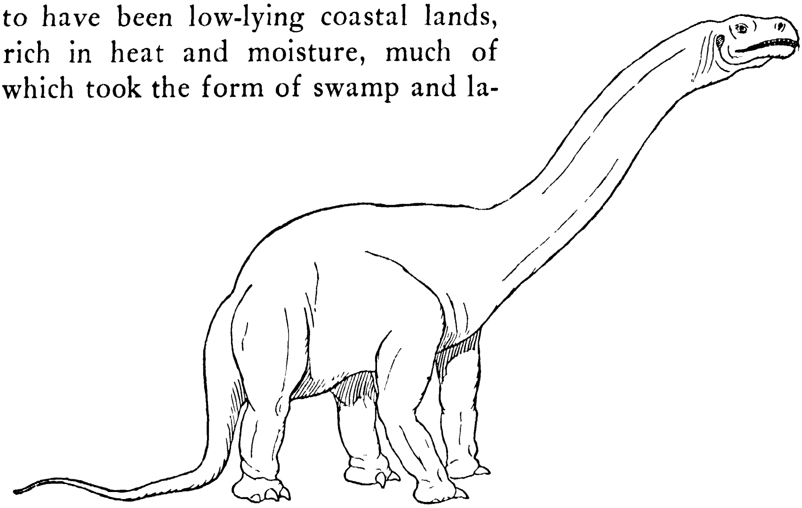


Fig 34—*BRONTOSAURUS EXCELSUS*

This huge animal (about 70 feet long) was partly, if not wholly, aquatic, a wading type with rather limited powers of swimming It must have fed on an abundance of some sort of water plants

From a restoration by the author after the specimen in the Yale Peabody Museum See frontispiece

goon or sluggish streams, and here the mightiest and weirdest of them lived.

The Jurassic Period

One of the more notable dinosaurs was the Upper Jurassic *Brontosaurus,* a huge animal measuring about seventy feet over the curve of the backbone, bearing its weight, estimated at thirty-seven tons, on four great pillar-like limbs. It had a rather short, compact body, but a long neck and tail and a relatively small head armed with spoon-like teeth in the front of its jaws. *Brontosaurus* is assumed to have been at least partly, if not wholly, aquatic, a wading type with rather limited powers of swimming. It must have fed on an abundance of some sort of water plants, although what they were has not yet been determined. These were dislodged by means of the clawed front feet, and devoured without mastication. In a comparable form, *Barosaurus,* there were found within the ribs a quantity of highly polished siliceous pebbles, which are supposed to have been con-

tained in a muscular stomach and to have aided in digesting the inert mass of food. *Brontosaurus*, although not the largest of dinosaurs, was, nevertheless, near the maximum size ever attained by any animal except some of the largest of modern whales, which because of their great girth and compact form, bulk vastly heavier at an equivalent length. Associated with *Brontosaurus* in time and habitat was *Allosaurus*, a thirty-four foot carnivore, with teeth like recurved daggers, and powerful talons borne on both fore and hind feet. The latter probably preyed on *Brontosaurus*, but whether it could slay one in the fullness of its strength, or whether the principal prey consisted of lesser dinosaurs, with an occasional dead *Brontosaurus* which it chanced to find, is not known. *Allosaurus* was certainly the most efficient beast of prey of his day—well weaponed, alert on his two hind feet, in every way eminently fit.

Another associate was *Stegosaurus* (Fig. 35), an armored dinosaur of lesser bulk, but of extreme grotesqueness, for the back of this quadrupedal form bore a double row of huge, upstanding plates, and the tip of the tail was armed with two or more pairs of spines formed of heavy bone, which, together with

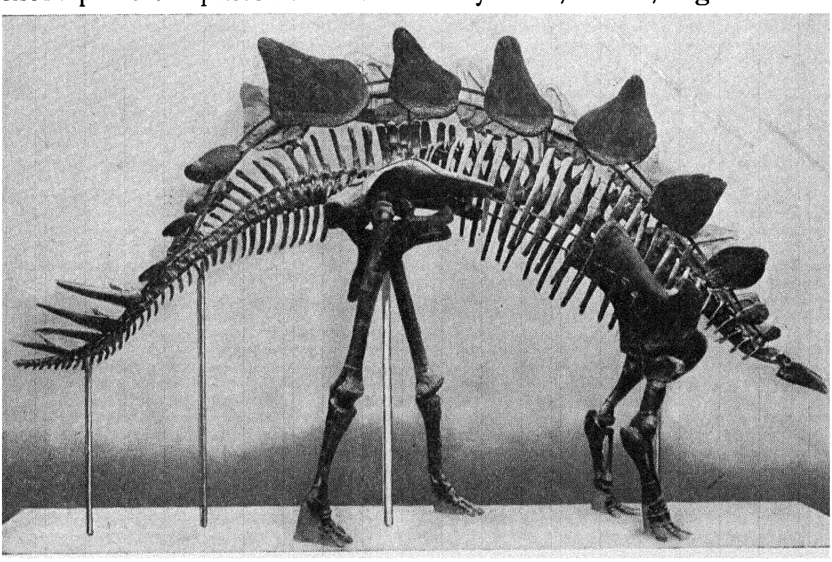


Fig. 35—SKELETON OF THE ARMORED DINOSAUR, *STEGOSAURUS UNGULATUS*, IN THE YALE PEABODY MUSEUM

Though the bulk of this animal exceeded that of the largest elephant, its brain was very small, not more than two and a half ounces in weight

the plates, must have been sheathed with horn. The small head bore a horny beak but rather feeble teeth, and the brain of this creature, whose bulk exceeded that of the largest elephant, was tiny—not more than two and a half ounces in weight. The brain was doubtless the seat of consciousness and of the interpretation of such images of sight and sound that came to it, but of intelligence it had hardly any at all. It was an excessively dull brute whose reactions were largely physiological, but which, together with its grotesque armor and armament, made for survival. *Stegosaurus* did not, however, continue beyond the Jurassic or early Cretaceous periods, although its relatives were able to carry on for a time.

There were also unarmored, bipedal plant-feeders among Jurassic types, such as *Camptosaurus* (Fig. 36). They were not yet conspicuous, although their descendants were to be when the giant amphibious dinosaurs had had their day.

The Cretaceous Period

In the Cretaceous the complexion of the dinosaurian societies changed. Gone are *Brontosaurus* and its allies, their place usurped by the types like *Trachodon* (Fig. 37) which not only could wade freely but, as the webbed hands and feet and the laterally compressed tail attest, could swim as well as a modern crocodile. The largest of these was about thirty-five feet, half the length of *Bronto-*

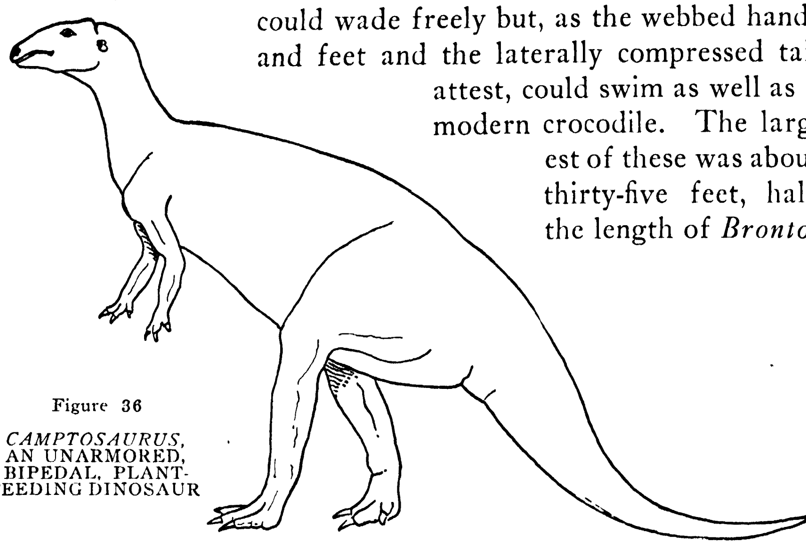


Figure 36

CAMPTOSAURUS, AN UNARMORED, BIPEDAL, PLANT-FEEDING DINOSAUR

It had an average length of about ten feet, and was found in the Jurassic period of North America

From a restoration by the author, based upon the skeleton in the American Museum of Natural History

saurus, and the weight proportionately much less. The skin, which is sometimes preserved, shows no trace of armor but was covered with small scales arranged in definite patterns. Its mouth armament, however, was remarkable. A broad, toothless beak, not unlike that of a duck in shape, covered either with a leathery or horny skin, formed the front or food-getting portion of the mouth. The rear half of each jaw bore within itself a wonderful battery of teeth formed in a number of vertical rows, which moved outward to compensate for wear, new teeth developing in the depths of the jaws. Thus each half of each jaw possessed some twenty-seven to thirty vertical rows of ten to fourteen teeth, making upward of more than a thousand, all told. And these are what the specimen now possesses and does not account for those which had been worn away by use.

In Europe, *Iguanodon* (Fig. 38), an earlier genus (Lower Cretaceous period), was comparable in appearance to *Trachodon* but without the extreme of specialization, except for curious, spike-like thumbs, apparently its only weapons. Certain American trachodonts, notably from Alberta, developed strange crest-like modifications of their skull, the meaning of which is not clear.

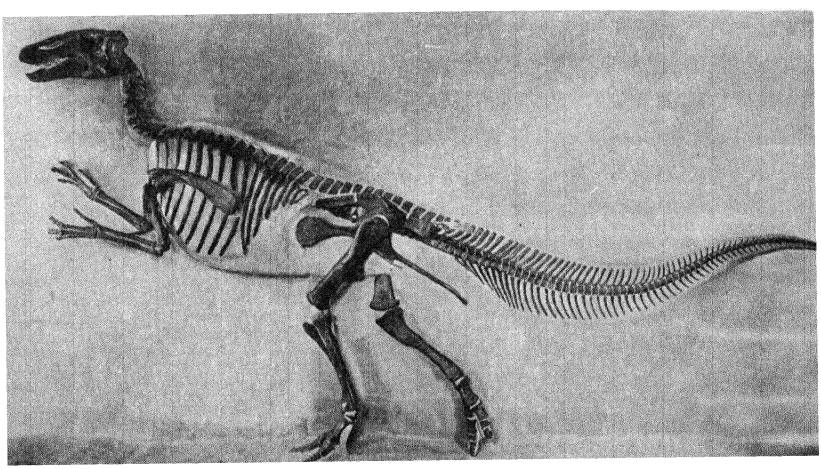


Fig. 37—THE DUCK-BILL DINOSAUR, *TRACHODON*

So called because of the broad, toothless beak which formed the front or food-getting portion of the mouth. The posterior part of the mouth bore a wonderful battery of teeth—more than 1000 all told

From a photograph of a skeleton in the Yale Peabody Museum

They have their analogy in the crests of certain birds and the various "ornamental" excrescences of modern lizards, the use of which, unless it be a sex distinction, is equally obscure. *Stegosaurus* had also passed away; but its group, the armored dinosaurs, was represented by yet weirder forms, like *Palaeoscincus,* or *Ankylosaurus,* heavily armored, spined and tubercled, with depressed, somewhat triangular, head, strongly beaked, but with feeble teeth or none at all. Their very immobility and heavy armor made these dinosaurs practically immune to successful attack.

Not all, however, were weaponless, for some had a great club-like expansion on the end of the tail, a veritable bone-crushing battle-mace, which, while clumsy, may have proved highly effective as a defensive organ when a carnivore had the hardihood to attack them.

Another group of dinosaurs are new to the scene, for we know of no Jurassic or early Cretaceous form which could pos-

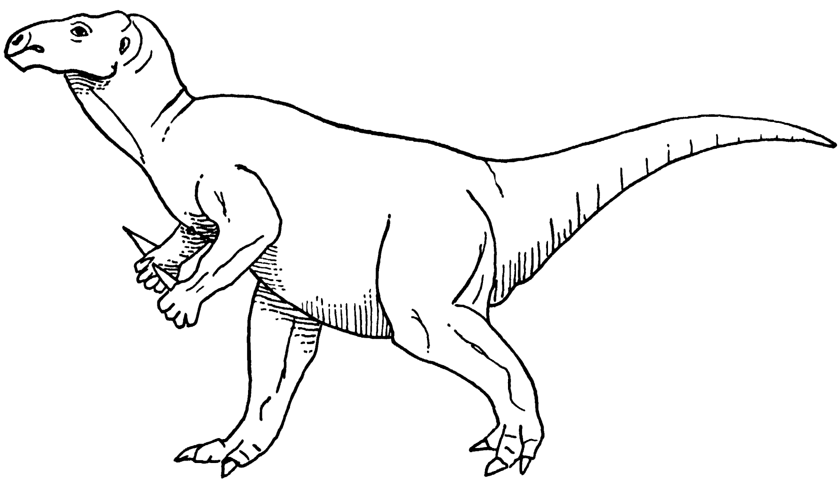


Fig. 38—ANOTHER BEAKED DINOSAUR, *IGUANODON*

No fewer than seventeen remarkably preserved skeletons were found in a coal mine at Bernissart, in Belgium, and are mounted in the Brussels Museum of Natural History. *Iguanodon* was about thirty-four feet in length, and bore upon the hand, by way of a weapon, a peculiar spike-like thumb

(*Adapted from Heilmann*)

sibly have sired them. These are the Ceratopsia, or horned dinosaurs, known, until recently, exclusively from the lands bordering on the eastern uplift of the Rocky Mountain region.

Ancestors which had all their characteristics, except the horns, have recently come to light in *Protoceratops* of far Mongolia. A typical American form is *Triceratops* (Fig. 39), from the uppermost Cretaceous beds, who was an associate in the rocks, if not in life, with *Trachodon* and the armored forms of which we have spoken.

In *Triceratops* the head was huge, being upward of one-third

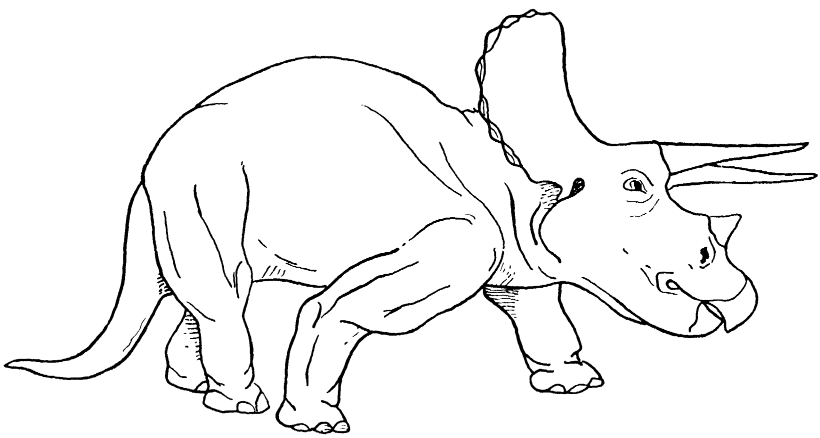


Fig. 39—*TRICERATOPS ELATUS*, ONE OF THE GREAT HORNED DINOSAURS WHICH LIVED IN THE CRETACEOUS PERIOD

It was about twenty-five feet in length, with a skull over eight feet long—the largest skull of a land animal known to science

From a restoration by the author, based upon the skeleton in the American Museum of Natural History

the overall length of the animal. It was borne on a bulky body with bowed forelegs and somewhat straighter hind ones and a rather short tail. The skull had a very small brain case, with a secondary over roofing of bone which was extended backward into an expanded crest or frill, which, during life, was closely invested with horny skin. This crest not only afforded leverage for wielding the head but also a protection for the nerves and blood vessels of the neck. A rather long face and deep muzzle, armed with a compressed turtle-like beak, completed the head, except for the horns. These were borne on the nose and above the eyes and vary greatly in their development in the different genera and species.

Monoclonius (Fig. 40), an earlier genus, possessed but one

horn, the nasal, but *Diceratops,* a contemporary of *Triceratops,* had two above the eyes, that over the nose having disappeared.

In most of the later dinosaur types the crest was a complete buckler of bone; in the earlier ones it was perforated by apertures varying in size and shape, and in one form, *Styracosaurus,* the outer edge of the crest bore huge horn-like spines. All were grotesque animals; but while reptiles, with all that that implies, they were very rhinoceros-like in general appearance. In size the largest *Triceratops* must have attained a length of twenty-five or more feet, with a skull over eight feet long—the largest skull of a land animal known to science.

All of these, *Trachodon, Palaeoscincus,* and *Triceratops,* were herbivorous, their arch enemy of the carnivorous phylum being *Tyrannosaurus* (Fig. 41), the most appalling devourer of flesh that ever stalked the earth. A ponderous body borne aloft on two massive legs armed with curved claws, and balanced by a heavy tail, *Tyrannosaurus* reared its huge head, with its cruel teeth, eighteen feet in the air. Its arms and hands were so very small that one cannot imagine why it had them at all, except possibly for pairing, but they show the tendency of evolution of the group, for while the other members keep pace with body bulk, the fore limbs become proportionately smaller and smaller until the marked disparity in *Tyrannosaurus* is reached. The latter, with its forty-five feet of length, was not only the most powerful but actually the largest dinosaur of its time and shows the final culmination of the race before ultimate extinction.

Fig. 40—THE HEAD OF *MONOCLONIUS*

A one-horned dinosaur which lived in the lowlands of what at present form the Rocky Mountain area of North America. Its huge horn and the great bony frill over the neck adapted it for both offensive and defensive operations

From a restoration by the author

But not all of the carnivores of that time were large, for there was a race of smaller and lighter beasts of prey, whose evolution has been traced from the Connecticut Valley forms, a foot or so in length, through *Compsognathus* of Solnhofen (Fig. 18), two and a half feet, to *Struthiomimus,* the ostrich-

mimic (Fig. 42), of the late Cretaceous period. This last, with its compact feet and toothless beak, resembled an ostrich in appearance, except for a long tail,

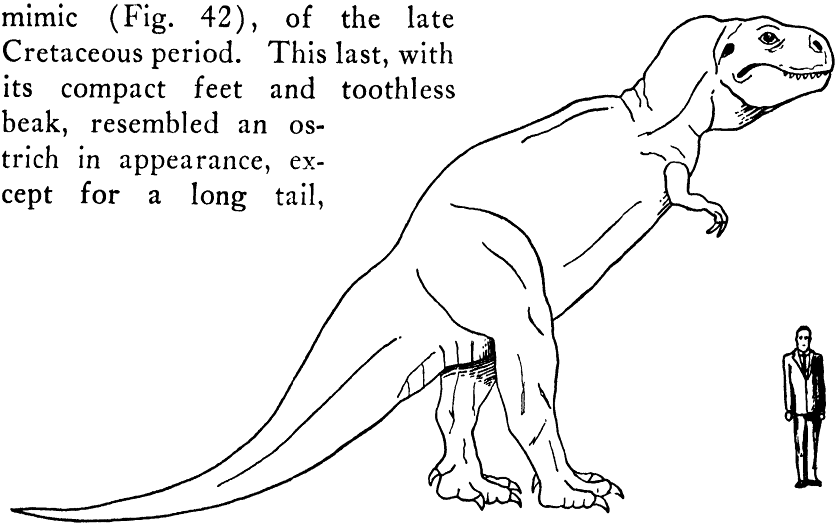


Fig. 41—*TYRANNOSAURUS*, THE LARGEST AND MOST POWERFUL CARNIVOROUS DINOSAUR OF ITS TIME

It was forty-five feet long and stood eighteen feet high, the entire weight of the body being supported on the massive hind limbs. The head was four feet in length, and the powerful jaws bore teeth from three to six inches long

From a restoration by the author

and doubtless was similar in its habits of life. It was by far the speediest among the dinosaurian horde.

Other Great Reptiles

Of marine reptiles there were several kinds, for no fewer than six reptilian orders took to the high seas for their livelihood during Mesozoic times. There were the turtles, crocodiles, mosasaurs or marine serpent-like lizards, allied to the monitors of today, and plesiosaurs with bulky body, four paddle-like limbs, and long neck bearing a quick, darting head which made up in its speed what the entire organism lacked. But perhaps the finest of all in its perfection of adaptation to marine life was the "fish lizard," Ichthyosaur (Fig. 43), stream-lined like a modern porpoise, with a long mouth armed with prehensile teeth, a powerful propelling tail with a vertical fin,

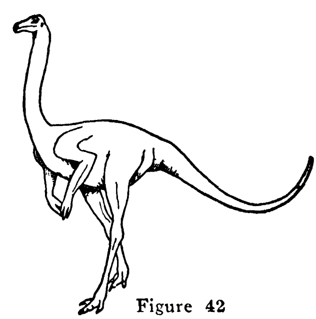


Figure 42

THE OSTRICH-MIMIC, *STRUTHIOMIMUS ALTUS*

By far the speediest among the dinosaurian horde

(Modified from Heilmann)

a dorsal fin, reduced hind limbs, and the fore limbs transformed into paddles. Not only were the ichthyosaurs dolphin-like in appearance, except that their tail fin was vertical instead of being horizontal, but their manner of life was the same, even to the feeding habits, for their coprolites show that their food consisted of fish and cephalopods upon which modern dolphins prey. They are totally unrelated to the whales, even though, like them, they brought forth their young alive; but they represent a marvelous instance of convergent evolution in which Nature has repeated herself, although with creatures of a totally unlike sort.

The air-minded reptiles were the pterosaurs or pterodactyls whose pinions differed from those of birds and resembled those of bats in that the supporting surface consisted of a fold of the

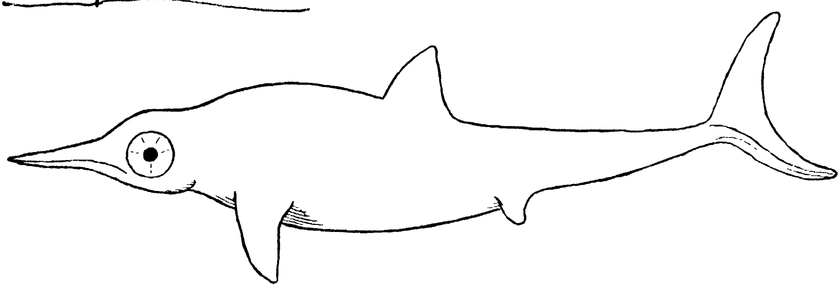


Fig. 43—THE MARINE REPTILE, ICHTHYOSAUR (*Stenopterygius*)
Dolphin-like both in appearance and in habits. It is an example of perfect adaptation from a terrestrial to an aquatic environment
From a restoration by the author, based upon the skeleton by Von Huene

skin borne by the arm, an elongated single finger, and a hind limb. In the Upper Triassic period pterosaurs appeared abruptly out of an unknown ancestry, enduring until the Upper Cretaceous time but dying out apparently before its close. Splendid examples, such as *Rhamphorhynchus* (Fig. 44), came from the Upper Jurassic bed at Solnhofen, but the culmination was *Pteranodon* (Fig. 45), a toothless form with fish-eating habits analogous to the existing pelicans. Pteranodon had a wing spread of upward of twenty-five feet—the greatest flying creature in Nature's realm. It is found in the Upper Cretaceous Niobrara deposits of Kansas.

These were but a few representative groups of reptiles; there were others, less spectacular, which made up the great reptilian dynasty of the Mesozoic.

Mesozoic Birds

Mention has been made of representatives of the two higher classes, birds and mammals, which also existed, but filled minor rôles in the medieval drama. Of the birds, the first was *Archaeopteryx* of Solnhofen (Fig. 46), so reptile-like in many ways that,

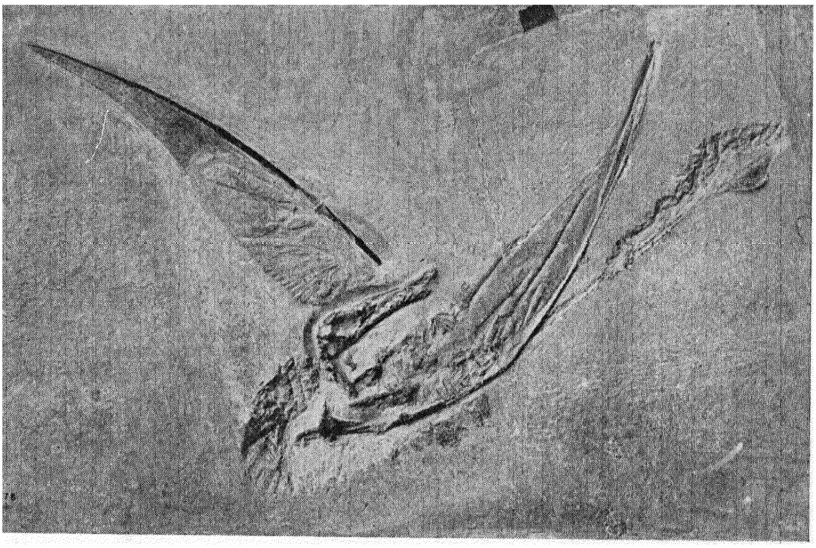


Fig. 44—THE GREAT FLYING REPTILE, *RHAMPHORHYNCHUS*

Even the impression of the delicate wing membranes is beautifully preserved

From a photograph of the Yale Peabody Museum specimen from the Jurassic deposits at Solnhofen

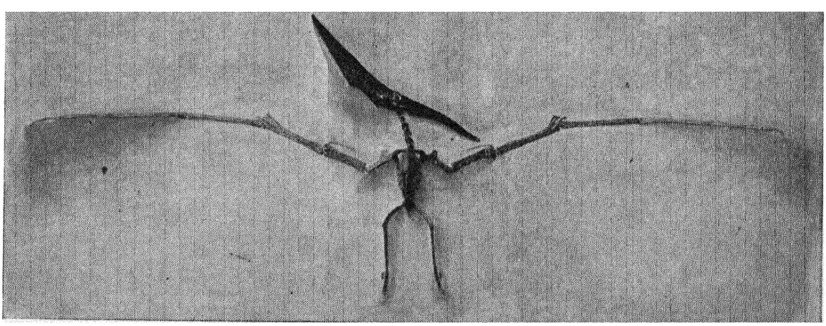


Fig. 45—SKELETON OF NATURE'S GREATEST FLYING CREATURE, *PTERANODON*

This specimen in the Yale Peabody Museum had a wing spread of eighteen feet. It came from the Cretaceous chalk strata of western Kansas

Fig. 46—RESTORATION OF *ARCHAEOPTERYX*, THE FIRST TRUE BIRD KNOWN TO GEOLOGICAL HISTORY

Though undoubtedly a bird, it had many reptilian characters, among which were the presence of teeth in both jaws, the free, clawed fingers of the hand, the poorly developed breastbone, and especially the long vertebrated tail, which, however, was furnished with feathers on both sides. In all later birds, the tail is short, and the feathers disposed fan-wise

(*From Heilmann*)

were it not for the preserved feathers, one would hardly be justified in assuming it to be a bird at all. Toothed, with feeble powers of flight, and a long lizard-like tail with a row of feathers on either side, these generalized forms were very different from the feathered songsters we know. Yet, had they not been discovered, they are about what one would predict for transitional forms from reptiles to true birds.

These Jurassic birds were succeeded in the Cretaceous period by *Ichthyornis,* not unlike the terns of today except that it also possessed teeth, and *Hesperornis,* a splendid creature nearly six feet in length, resembling a large flightless diver (Fig. 47). *Hesperornis* was also toothed, but its wings were reduced to a pair of long slender upper arm bones. Even the breast bone had lost the keel, to which the great muscles of flight are normally attached, in a manner comparable to that of the modern flightless birds, like the ostrich. But there the ostrich-like character ends, for *Hesperornis* was a marine bird, of habits analogous to the existing loons. Our fossil record of birds is always meager, for they rarely are entombed as are other forms of life.

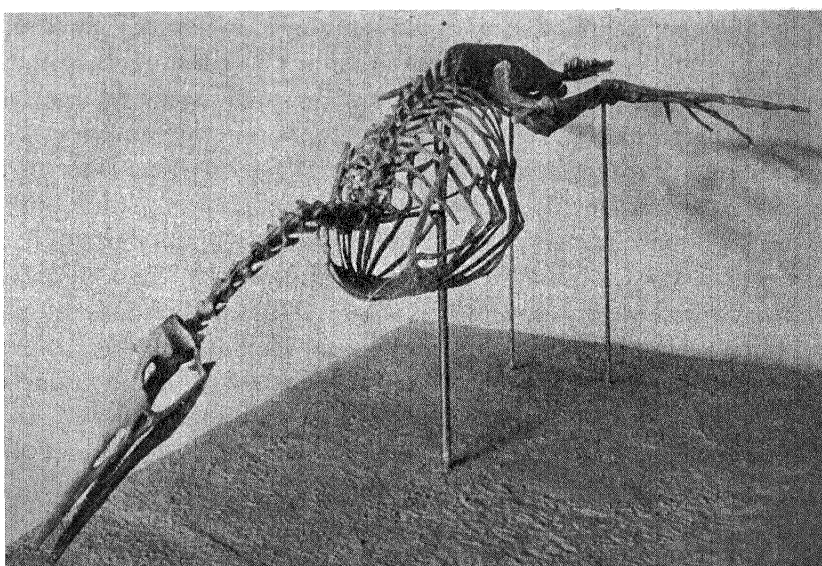


Fig. 47—THE SKELETON OF ONE OF THE TOOTHED BIRDS, *HESPERORNIS*

This specimen in the Yale Peabody Museum came from the Niobrara formation of Kansas. It was about four and a half feet long, had lost the power of flight, but had developed powerful hind limbs well adapted for swimming

We are fortunate in that the three or four Mesozoic birds which we have are in so high a degree of completeness. They are, however, all marine and are all toothed. If we knew the true land birds of the Mesozoic, of graminivorous habits, it is highly probably that we might find toothless ones in every way comparable to those of today, though without their range of specialization in numbers and kinds.

The Warm-blooded Mammals

The warm-blooded mammals are the familiar quadrupeds or beasts of today, and though neither title properly applies to mankind, man nevertheless belongs to the class. Their advent in geological time is therefore of double interest to us, both on account of our many contacts with the "beasts of the field" and also because of our lineage. Mammals arose out of a group of reptiles known as cynodonts (*i.e.*, dog-toothed), primitive in many respects, but differing particularly in their dentition, for while with reptiles in general teeth may vary in size in certain parts of the mouth, here they are clearly differentiated into incisors, canines, and cheek teeth, as in a mammal. Cynodonts are found in continental strata of Triassic age in various parts of the world, but especially in what is known as the Karoo formation of South Africa, which contains also undoubted mammals.

All of the known mammals of the Mesozoic era have the common property of small size, averaging up to that of a rat, although certain skulls from central Mongolia indicate somewhat larger creatures. None is large, however, in the sense that the reptiles were. The remains, though locally fairly abundant, are nevertheless among the rarest of fossils of Mesozoic time, and in no known instance has anything approximating a complete skeleton been found. On the contrary, the fossils are extremely fragmentary, consisting principally of isolated teeth, many jaws, both upper and lower, rare portions of skulls, only three or four of which are fairly perfect, and a few skeletal elements, which never, so far as known, can be associated with their appropriate jaws and teeth. Thus it is obvious that we can have no clear vision of a complete animal, such restorations as have been attempted having a large degree of conjecture and inference from related forms of the Cenozoic era.

We know, however, that the Mesozoic mammals differed markedly in tooth structure and hence in feeding habits, that some were vegetarians and others devourers of animal life, although from their lack of prowess, the prey of the latter must have been proportionally feeble. The insectivores of today feed upon insects, worms, grubs, small reptiles and birds; so must it have been with the carnivorous mammals of the Mesozoic era. Two of the most productive localities in America are the Como Bluff, of Jurassic age, where they were associated with the great dinosaurs, *Brontosaurus, Allosaurus,* and others, and the Cretaceous beds of Niobrara County, which produced *Triceratops, Trachodon,* and *Tyrannosaurus.* These localities are both in Wyoming. In every instance mammals are associated with dinosaurs, which implies the same geological and geographical distribution, but not necessarily the same environment, for Dr. William Diller Matthew (1871-1930), of the University of California, thought that the Mesozoic mammals were largely, if not exclusively, tree-inhabiting, whereas the dinosaurs were terrestrial or partially aquatic.

It is possible that future research may reveal as yet unknown areas in which, on account of different conditions of environment, mammals may be found differing markedly in size and in other characters from those we now know. In the light of our present knowledge, the most amazing thing about them is their apparent stagnation, for, aside from tooth detail, they show little evolutionary advancement from their first appearance in Upper Triassic rocks until the close of the Cretaceous, over 100 million years! This is the more surprising when one remembers that out of some Mesozoic mammals, known or unknown, are to arise all of the higher orders. The potentiality to evolution must have been there, and, if so, it was held most effectively in check, presumably by the ruling dynasty, the reptiles.

Extinction of the Great Reptiles

Reptilian extinctions which occurred with such apparent suddenness at the close of the Cretaceous, leaving but few survivors out of the many orders of highly efficient creatures, were of paramount importance for the mammals. Occasionally Nature seems to wipe the slate clean of once dominant forms and start

afresh with creatures whose rôle had been one of subordination and thus people the world anew. So it was at the end of the Mesozoic era. How this was brought about is a mystery, though a number of explanations have been offered. Were we thinking of dinosaurs alone the problem would be simpler, but the great extinction swept the reptiles from the high seas and from the air, as well as from the lands.

The close of every era, Paleozoic, Mesozoic, and Cenozoic, has been marked by great geologic change; orogenic, or mountain-making movements, are everywhere manifest, and, whatever their influence on climate, they are critical periods for animal life, for always when these "revolutions" are past old familiar types are among the missing, evolution is accelerated, and new groups arise.

Not always is plant evolution synchronous with that of animals. In fact it usually precedes the latter. Thus, while plants became fully modernized during the Cretaceous period, the dinosaurs still held sway and adapted themselves to the changed appearance of the plant world without marked change on their own part. This but adds to the difficulty of the problem.

The Cenozoic Era

With the passing of the reptilian dynasties the mammals come into their own and in their turn become what we have called dominant forms of life. It is interesting to note that each wave of dominance arises out of what were humbler and less specialized forms. Dominant never produces dominant of the same lineage. It is a *replacement,* not a succession in the sense of related beings, as the succession of the kings of the house of Stuart or of Hapsburg.

The Archaic Mammals

Two successive waves of mammalian evolution occur in the Cenozoic era, the first of which immediately followed the extinction of the great reptiles. This concerns the so-called "archaic mammals" which, while showing remarkable adaptations in many respects, are also characterized by certain constitutional inhibitions which apparently they were unable to overcome and which were so serious as to doom them from the start.

There are three essentials of mammalian evolution, the first two of which are the feet and the teeth, which are perhaps the parts of the animal most closely in contact with the environment and which were the concern of the reptiles as well. In the Cenozoic era to these two was added the brain, and for the first time a premium was placed upon the psychological aspect of an animal's fitness for survival. This was largely unessential in the reptilian evolution. The archaic mammals possessed all three; but in no instance within the group were they capable of the development and specialized adjustment which their modernized successors displayed, for out of the latter, with few exceptions, the existing mammals have come. Their feet were always primitive—five-toed, clawed, or hoofed—but never capable of such specialization as occurs in a horse or cat. The teeth, while differentiated and in rare instances specialized as to tusks, never showed, especially in the molars, a perfection of adaptation to a particular diet, such as grass or flesh. Finally, the brain is actually small in proportion to the bulk of the animal, although far better in this respect than in the reptiles. Casts of the interior of the brain-case, either natural or artificial, give an excellent replica of the vanished organ. While the parts which have to do with sense perception and muscular co-ordination are fairly well developed, the cerebral hemispheres, which are the seat of intelligence, are relatively very small and their outer surface is smooth, showing a very limited cortex, the so-called "gray matter" of popular usage. These were altogether stupid beasts, well enough perhaps when all were of the same degree of mentality, but unable to cope with the invading army of intelligent, modernized creatures which shortly overwhelmed them.

Several orders of mammals are classed as archaic. They make their appearance in the opening period of the Cenozoic, the Paleocene, and all but one or two genera have disappeared by Oligocene time, unless certain groups, such as the sloths and armadillos and the pouched marsupials, are living survivors. The most notable among the archaic mammals were the creodonts, primitive flesh-eating animals of greater prowess than the Mesozoic carnivores. Some of these were weasel-like, some resembled the dogs, others were hyena- or bear-like, and doubt-

less of comparable habits in each instance. A very dog-like form is *Dromocyon* (Fig. 48), from the Bridger Eocene strata of Wyoming; the skull of a gigantic type, *Andrewsarcus,* was discovered in Mongolia by the American Museum expedition of 1923. *Dromocyon* has a large head in spite of the small brain-case, size being necessary to provide attachment for the large muscles which the inefficient teeth required for anything like effective use.

In addition to the creodonts, there were two orders of herbivores, the condylarths and the amblypods. Of these the first were, on the whole, lighter of build and more or less adapted for speed; in fact, they paralleled the creodonts rather closely, except for the contrast of diet which their teeth indicate. One

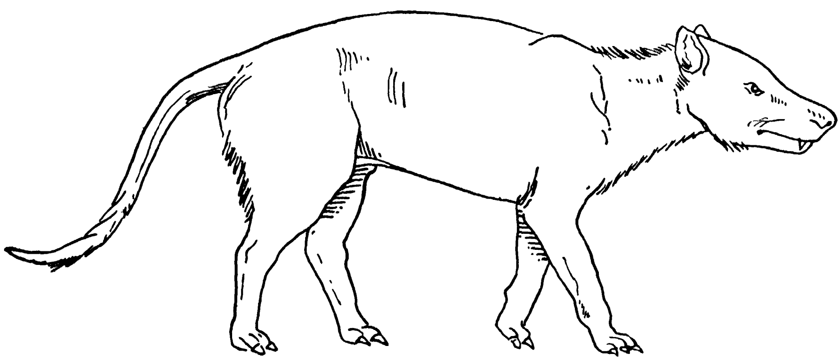


Fig. 48—*DROMOCYON VORAX,* A DOG-LIKE CREODONT FROM THE MIDDLE EOCENE STRATA OF WYOMING

In spite of its comparatively large head, this archaic mammal possessed an extremely small brain-case

From a restoration by the author, based upon the skeleton in the Yale Peabody Museum

notable specimen was *Phenacodus primaevus,* an animal about the size of a sheep (Fig. 49). This was discovered years ago in the Bridger beds of Wyoming by the noted American paleontologist, Edward Drinker Cope (1840-1897), and is now in the American Museum of Natural History. When first found, Dr. Cope hailed it as the five-toed ancestor of the horse, which has been ardently sought for, thus far without success. The large size and inadaptive characteristics, together with the fact that it is contemporaneous with *Eohippus,* the four-toed horse, debars it absolutely as the forerunner of a proud lineage.

The amblypods were, as a rule, much larger than the con-

dylarths, heavy-bodied and ungainly, with stumpy or splayed five-toed feet. Of these, *Coryphodon* (Fig. 50), again from the

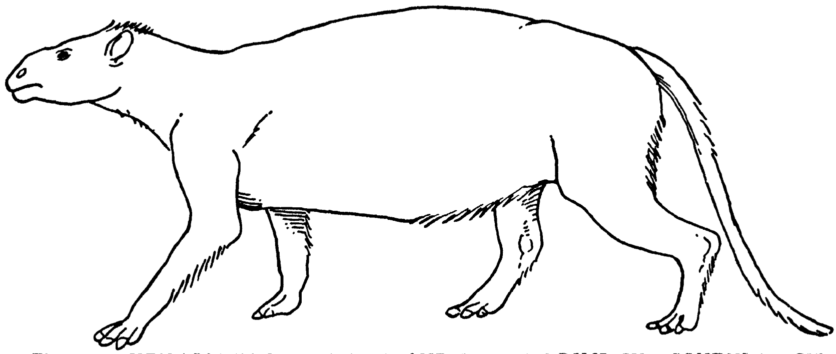


Fig. 49—*PHENACODUS PRIMAEVUS*, ONE OF THE PRIMITIVE CONDYLARTHS

It survived until the end of lower Eocene time and was a contemporary of Eohippus

From a restoration by the author, based upon the skeleton in the American Museum of Natural History

Bridger, was about the size of a small rhinoceros, with flaring tusks almost like those of a wild boar, and an absurdly small brain. The character of the feet indicate a swamp-dwelling creature.

The culminating amblypod, by far the most grotesque of

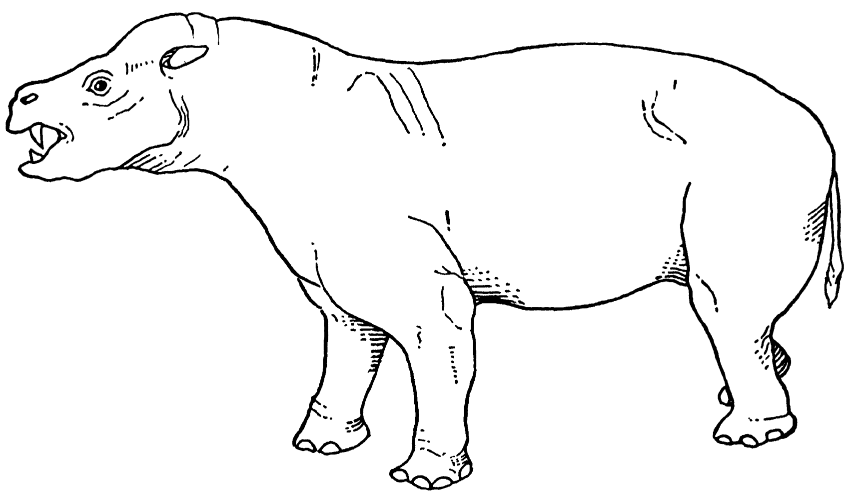


Fig. 50—*CORYPHODON HAMATUS*, AN AMBLYPOD FROM THE BRIDGER BEDS OF WYOMING

It was about the size of a small rhinoceros, with flaring tusks almost like those of a wild boar

From a restoration by the author

all the archaic mammals, was *Dinoceras* (Fig. 51). Large, almost elephantine of body and limbs, standing about six feet at the withers, this strange brute had a most unusual head. It was rather long, with three pairs of horn-like eminences on the skull, a pair on the nose, one above the eye, and again a pair at the hinder end. These were doubtless sheathed with horn and may have served in a measure as weapons. *Dinoceras* was further provided with a pair of dagger-like tusks, the canine teeth of the

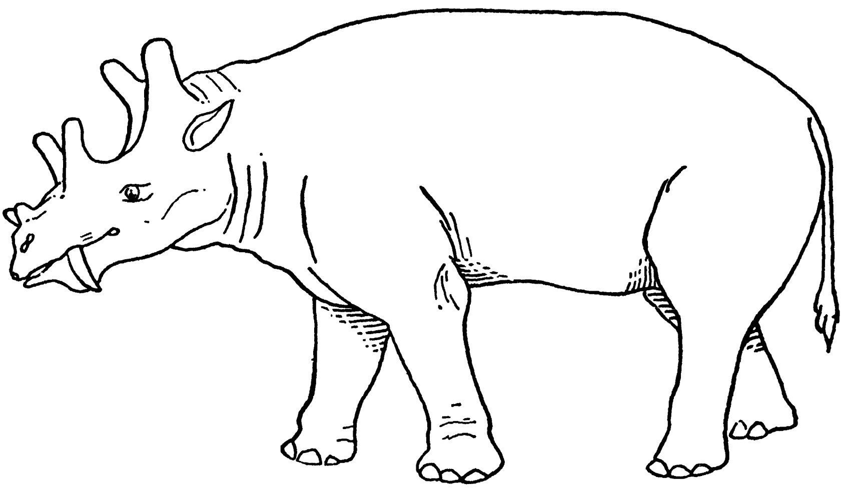


Fig. 51—*DINOCERAS INGENS*, THE MOST GROTESQUE OF THE ARCHAIC MAMMALS

It was almost elephantine in body and limb, standing six feet at the withers. The armament of *Dinoceras* may have served a useful purpose, but it is more likely an indication of racial senility

From a restoration by the author

upper jaw, which pointed downward and were protected, when the mouth was closed, by a large bony flange on the lower jaw. The tusks and horns vary with the species and sometimes within a species, possibly as a sex character, the more heavily armed individuals being apparently the males.

Dinoceras first appears in the Bridger, Middle Eocene, beds and ranges up into the Uinta formation, the closing member of Eocene time, during which a marked evolution of the skull, horns, and tusks is seen. The molar teeth, however, are practically unaltered in form and size, in spite of the changes in the skull and armament. They are a curious illustration of a veneer of specialization in a primitive beast. The brain, although larger

than that of *Coryphodon,* is still very small compared with the elephantine bulk of its owner. These archaic mammals evidently had their origin, as well as their subsequent evolution, largely in the western part of North America, being found chiefly in Wyoming.

The Modernized Mammals

In the meantime, however, there begins the invasion of middle North America by the advanced scouts of a conquering army, the modernized mammals, which, as we have mentioned, include the actual forebears of the existing beasts and of men. These forms had no such constitutional limitations as had the archaic, for the three essentials, feet, teeth, and brain, are potentially capable of the highest specialization. But not all of the modernized mammals developed the three equally well; the horses "elected" development in each, the elephants in two, the teeth and brain, retaining primitive feet, whereas human evolution has stressed but one, the brain, the teeth being extremely primitive, the hands as well, while the feet show a little specialization, but not much as compared with many other mammals.

The rather sudden and simultaneous appearance of the modernized mammals in both the Old World and the New, points to an origin and initial evolution in some region contiguous to both. If one looks at a polar projection of our earth, in the northern hemisphere, he will see the great continental masses converging toward the pole and radiating outward toward the south. The circumpolar area, therefore, forms with a few breaks a common land from which lines of migration run down the continental axes, the Americas, Europe and Africa, and Asia. While there is no direct evidence, such as the finding of circumpolar fossils, that region is the only one from which these creatures could have come in order to arrive simultaneously, as they did, in the several remote lands.

The climate of this northern land was mild, but apparently variable, which is always a higher stimulus to progress than would be the warm, moist, uniform climate of the Eocene period in Wyoming. This may have made possible the evolution of the higher types in the north rather than in Wyoming. The

southward migration seems to have been caused in part by climatic pulsations, tending toward greater severity, for the animals come not all at once but in a series of invading waves and in part by pressure of numbers, which always impels migration wherever possible. At once the invaders entered into competition with the archaic mammals, the fate of which is doubtful except that they disappeared from their old territory forever. Some were driven southward where they formed some part of the curious South American and African faunae; others, unable to endure the competition, finally became utterly extinct. Yet others, and these were very few, may have given rise to some at least of the existing animals, possibly the true Carnivora. The modernized mammals now possess the land. We have space for the consideration of very few, but the three groups mentioned above, horses, elephants, and humanity, should be described—the first because of the completeness of our record of the stages which link the earliest, *Eohippus,* with the horses of our time; the second not quite so complete, but of great interest; and the third, though the least perfect of all, because of the personal appeal.

CHAPTER VII

FOSSIL HORSES

YEARS of exploration in Europe and North America have given our museums a wonderful array of fossil horses. When a few had been found, the line of evolution was thought to be a single straightforward thing; but with the abundance of material the problem becomes complex and we find several parallel and divergent descent lines, some of which died out from time to time until one genus alone survives, although in several markedly different species.

THE DIFFERENCES BETWEEN THE HORSE AND HIS UNKNOWN ANCESTOR

The recorded evolutionary changes are, briefly: (1), increase from three to sixteen hands in shoulder height; (2), increase of about 200 times in bulk; (3), a change in the dentition from short-crowned grinders bearing a half-dozen or so isolated cusps to more complex grinders and enlarged cropping teeth; (4), an increase in length and in simplicity of the feet as an adaptation for speed.

In the evolution of the teeth, the isolated cusps fused into crests, the valleys between the crests becoming flooded with cement, and the teeth lengthened, becoming prismatic with elaborate patterns caused by the infolding of the outside enamel. The premolars, at first simpler than the molars, became successively molar-like, beginning with the hindermost, until instead of four premolars and three molars, there were six grinders in each half jaw, all essentially the same in appearance, while the first premolar had become the vestigial "wolf tooth." In the modern horse, the jaws have elongated and deepened to give room for the increase in size of the teeth and the separation of the cropping teeth from the grinders by the gap or diastema.

The unknown hypothetical ancestor was doubtless five-toed

both in front and behind, the bones of the hand being suggestive of our own. Gradually the hands and feet were raised higher on their digits, of which the third or middle one was destined to bear the most weight. The lateral toes diminished proportionately, starting with the first, then the fifth, and finally the second and fourth together, so that there are four-toed horses known to science, then three-toed, and finally one-toed, but never two-toed. In the final stage, vestiges of digits two and four remain as splints on either side of the canon bone, just as in earlier stages vestiges of the first and fifth remained for a time after the real toes had disappeared.

The Ten Stages in the Evolution of the Horse

In the actual fossil record there are ten stages recognized as characteristic of the successive geological horizons—not that this implies abrupt changes but quite the contrary, for it is obvious that to have a complete series there should be a specimen of each generation, a manifest impossibility. The geological horizons, as we have seen, are separated by time intervals during which a break in the continuity of sedimentation occurs. The specimens of these lost intervals, which may represent many generations, are also lost, hence the apparently abrupt change when the fossils reappear. The several stages are as follows:

1. *Eohippus,* the first known stage in the evolution of the horses, is found in our West in rocks of Lower Eocene age and their equivalent in the Old World. The European form, *Hyracotherium,* of the London Clay is somewhat more primitive in tooth structure and, therefore, possibly older. *Eohippus* had four toes in front and three behind, for at first the evolution of the foot is more rapid than the hand, due in part to its having a somewhat greater share in the propulsion of the animal. The height at the shoulder was about eleven inches, the back was arched, and the head and neck were rather short, but *Eohippus* had moderately long limbs, the proportions being not unlike those of the racing hound known as the whippet. It must, therefore, have been an animal with a fair turn of speed for its size. The teeth were short-crowned, with the primitive cusps beginning to fuse into crests. This genus had a remarkable geographic range, for, after evolving in some northern area, it migrated

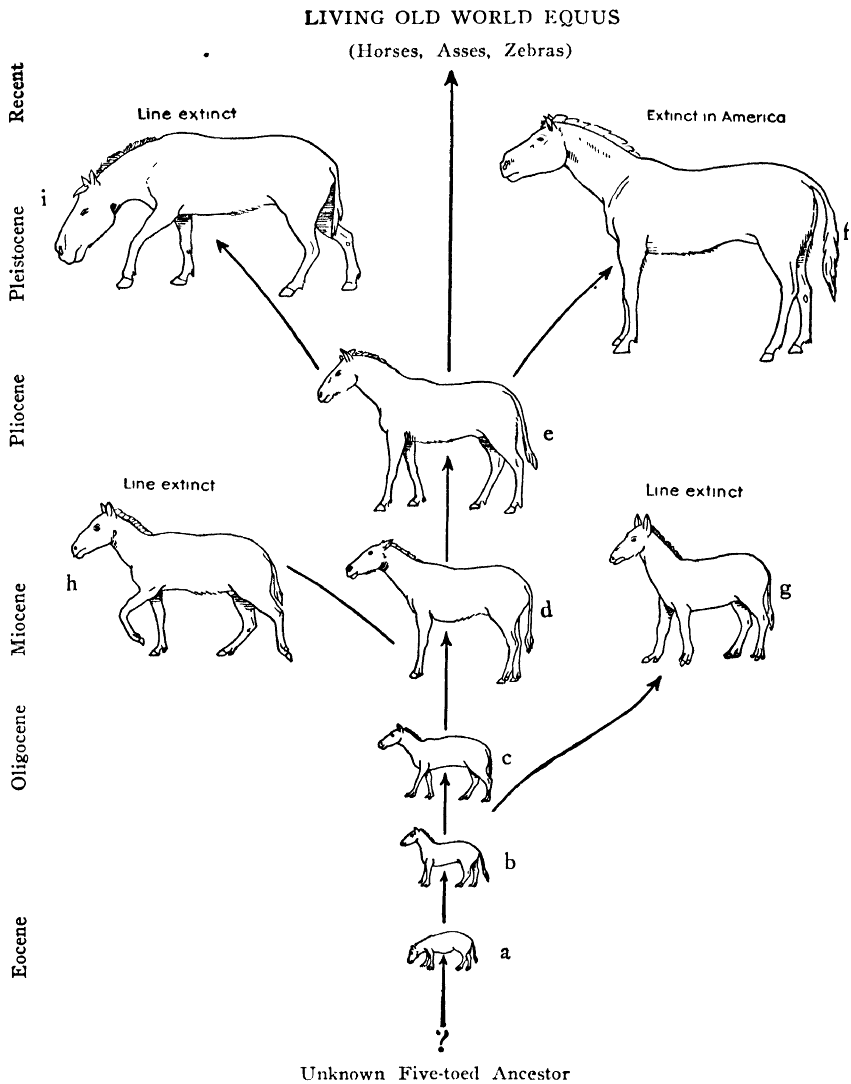


Fig. 52—PHYLOGENY OF HORSES

a, Eohippus; b, Orohippus; c, Mesohippus; d, Merychippus; e, Pliohippus; f, Equus; g, Hypohippus; h, Hipparion; i, Hippidium

Horses a-f represent the main line of descent; g, h, and i, collateral lines which have become extinct

(*After Lull*)

southward as far as New Mexico in the New World and Europe in the Old.

2. During Eocene time the horses increased in size and suffered further diminution of the fourth digit of the hand, but all are four-toed horses nevertheless, although other generic names are applied to them, *Orohippus* of the Middle and *Epihippus* in the Upper Eocene.

Although in America the horses form a continuous series from *Eohippus* to *Equus,* in the Old World the line is broken from time to time. It is assumed, therefore, that the real theater of their evolution, after the initial appearance, was North America, from which they migrated, as opportunity arose, via one or more land bridges over which traffic was not, however, continuous. What caused the repeated extinctions in the Old World after each invasion is not clear, for at the end the conditions were reversed and final extinction occurred in the New World and survival in the Old.

3. *Mesohippus* was the first three-toed stage, for now the hand, except for a vestige of the fourth digit, had overtaken the foot in its evolution, and henceforth their development is comparable. *Mesohippus* also varied in size but averaged eighteen or more inches in height, was slender-limbed and better adapted for speed.

4. *Miohippus,* the fourth stage, differs but little from its predecessor except in size, which is increased to twenty-four inches. *Mesohippus* was Lower and Middle Oligocene, whereas *Miohippus* comes from the upper beds. A derivative of *Miohippus* known as *Anchitherium,* made its appearance in Europe in the Miocene, the result of the second migration.

The climate of the Eocene and the Oligocene periods was warm and moist, with an abundance of succulent vegetation for these small browsing horses. But in the latter period there is already an expansion of grasslands, prophetic of the widespread prairie conditions which the growing aridity of the Miocene was to foster.

Miocene horses are several, not all of which were in the direct line of descent; all were three-toed, however, although varying in the development and utility of their lateral toes. In the main line were:

5. *Parahippus,* yet a browsing horse with short-crowned teeth.

6. *Merychippus,* forty inches tall, whose milk teeth were short-crowned but whose permanent grinders were prismatic with infolded enamel, an adaptation to harsher herbage.

7. *Protohippus,* whose milk teeth as well as the permanent set were long-crowned.

Three or more side lines occur: *Anchitherium,* to which reference has already been made; *Hypohippus,* pony-like in size, with well developed side toes, thus adapting the creature for yielding ground, and short-crowned teeth set in shallow jaws. *Hypohippus* is sometimes described as a forest horse, but the feet are analogous to those of the reindeer which is adapted to the mossy tundras. At all events *Hypohippus* was not a prairie horse, and by the beginning of the Pliocene it became extinct as a race.

A third collateral line was *Hipparion,* again a migrant to the Old World where it survived until near the close of the Pliocene. Still three-toed, with lateral digits that occasionally touched the ground when the going was soft, *Hipparion* had the most complicated teeth thus far recorded. It stood about forty inches at the shoulder, a speedy creature of somewhat deer-like proportions. *Hipparion* also died without further issue, leaving the main stream of equine blood to

8. *Pliohippus* of the Pliocene, the first one-toed horse, although some of the species of this genus may have retained small, practically useless, side toes, like the "dew claws" of cattle. By Upper Pliocene time, *Pliohippus* had merged into

9. *Plesippus,* whose lateral toes had entirely disappeared and whose stature almost equaled that of *Equus,* which still lives in the modern horse.

10. *Equus* is Pleistocene in time and had spread to South America as well as to the eastern hemisphere. Then came the final extinction of the horse in the Americas, of which we cannot yet clearly define the cause, for, whatever it was, it did not affect either the Asiatic or African horses, although as wild animals they have also disappeared from Europe.

The Pleistocene period was characterized by the mantling of the northern continents with vast sheets of ice, which flowed

and ebbed and flowed again, there being in America four, possibly five, periods of advance separated by much longer periods of mild and even salubrious climates. In the southern hemisphere the ice was more local, existing not as continental ice sheets such as still mantle Greenland and Antarctica, but as alpine glaciers in the vicinity of which domestic horses live and thrive.

Some devastating insect-carried disease, such as the sleeping sickness of Africa, or the surra disease of India, has been suggested, brought in by some invading mammals which could carry the parasite and yet, themselves, be immune to its effects. An insect, such as the tsetse fly of Africa, is the intermediary between one mammal and another. That the Americas are now a splendid horse environment is attested by the hordes of wild, or secondarily wild, horses, the mustangs, which have overrun both continents from a very small beginning—the few horses brought over by the Spanish conquerers and left behind when they had no further use for them.

This we know, that the Glacial period was a very critical time for animal life, although in just what way the influence was felt is still obscure. At all events, many splendid forms fell before its onslaughts, including the native American horses. In Asia and Africa, on the other hand, the indigenous horses still survive, the Prjevalsky horse and the kiang of Mongolia, the Nubian and Somali asses of northern Africa, the first to be domesticated, and finally the African zebras. Were it not for the final migration of *Equus* to the Old World, man's most faithful companion, with the exception of the dog, and certainly the companion to which his civilization owes the most, would never have been available, and as a consequence his march of culture and commerce would have been retarded immeasurably. It is said that the mysterious Maya civilization of Central America is the only one which has ever arisen among people who possessed neither metal tools nor the horse.

CHAPTER VIII

FOSSIL ELEPHANTS AND MASTODONS

ELEPHANTS and mastodons are included in the Proboscidea, a group of hoofed animals characterized briefly by gigantic size and the possession of the trunk, or proboscis, which gives its name to the race. The size necessitates pillar-like limbs to carry the weight, borne on rather primitive five-toed feet, although there is a tendency toward the loss of one of the hinder toes. The skeleton of the foot is encased in a yielding cushion around which are nail-like hoofs which may be fewer in number than the actual digits. Most long-limbed animals possess an equivalent length of neck in order to enable them to reach the ground. But not so here, for, because of the great, heavy head, the neck is short and thick, and the proboscis serves the purpose of food and water getting and other minor uses as well.

ADAPTATIONS OF SKULLS AND NOSES

The skull has changed its shape from the long, low form of the average quadruped and has become short and high to gain leverage with which to wield the trunk and tusks. This only in part involves the actual brain chamber which, in itself, has over twice the capacity of a man's. The skull walls have become enormously thick through the growth of cellular bone, known as diploë, between the inner and outer surfaces of the original skull bones. This has increased the leverage and the area for the attachment of the neck muscles and ligaments without undue increase in weight.

To the face is attached the proboscis, the combined upper lip and nose through which the nostrils run for its entire length. The organ contains some 500 muscles and possesses not only great power but dexterity as well. In the Indian elephant it terminates in one and in the African elephant in two finger-like processes for grasping.

Peculiar Dental Features

The proboscidean teeth are remarkable for their fewness at any one time, their complexity of structure, and their manner of succession in the jaws. There are in the adult elephant but six fully formed teeth in the mouth, although when a grinder is partly worn away its successor may be seen in partial use. The tusks are long, curved, tapering teeth, originally the second pair of upper incisors. These grow continuously throughout the lifetime of the animal. The grinders are complex, being formed of double plates of enamel, each pair enclosing a portion of dentine and separated from the adjacent pair by a layer of cement, the whole being bound together into a single organ. As the softer dentine and cement are worn away, the enamel, being by far the hardest, is left in the form of transverse ridges, thus producing a roughened grinding surface. The number of ridges varies from six to twenty-seven or more in a single tooth. These grinders are formed successively in the rear of the jaws and move downward and forward through the arc of a circle as the ones in use wear away.

From Moeritherium to Mastodon and Elephant

The first proboscideans are found in the Egyptian Faiyum desert, some sixty miles southwest of Cairo. The ancestral form is *Moeritherium,* named after the ancient Lake Moeris, in the sediments of which it came to light. *Moeritherium* was a small Eocene form not over twenty-five inches in height, with a long, low skull and the normal vertical tooth succession of a mammal. There were three pairs of upper incisors of which the second are already the largest. The grinders were simple, short-crowned, with two or three cross crests. The proboscis has not yet appeared; whether or not the animal even had a prehensile lip is a matter of differing opinions. The body characteristics are not well known.

Paleomastodon

Moeritherium was succeeded by *Paleomastodon* in the Lower Oligocene of the same region, the former persisting for a while with the newly arisen form. The skull of *Paleomastodon* is larger

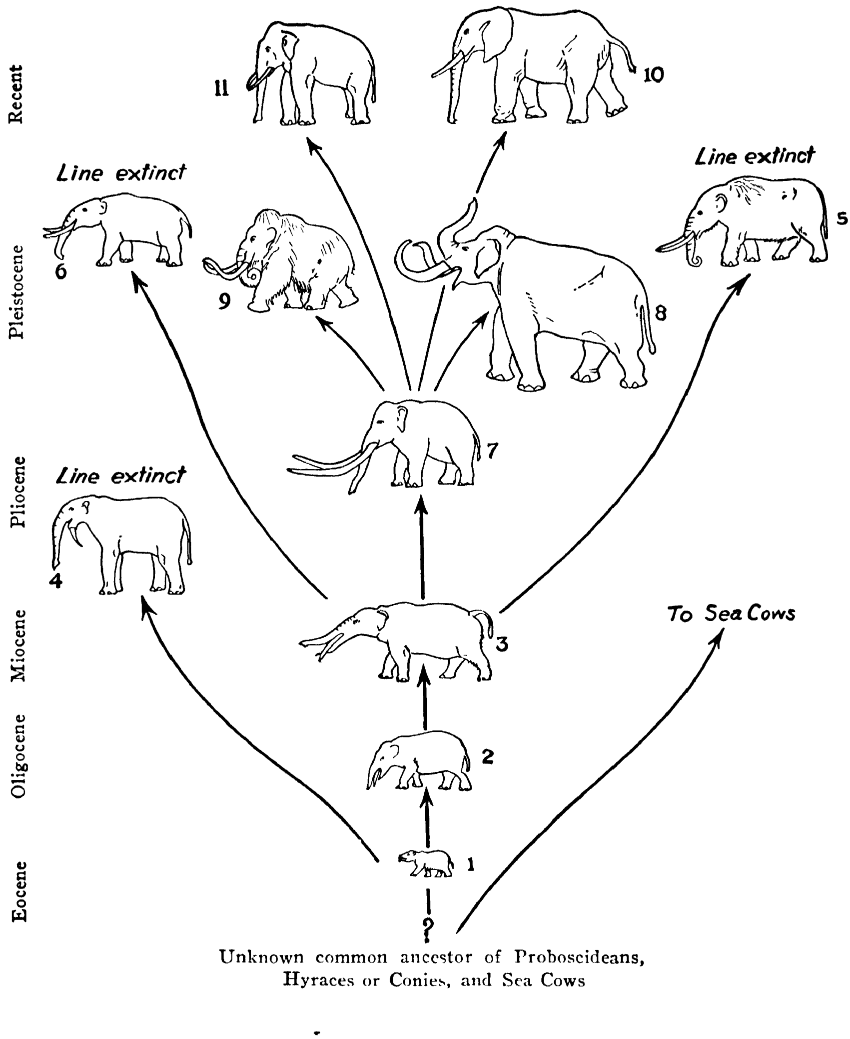


Fig. 53—PHYLOGENY OF THE PROBOSCIDEANS

1, Moeritherium; 2, Paleomastodon; 3, Trilophodon; **4**, **Dinotherium**; **5**, **Mastodon**; 6, Dibelodon; 7, Stegodon; 8, Imperial Elephant; **9**, Woolly Mammoth; 10, African Elephant; 11, Indian Elephant

Drawn to scale

(Modified from Osborn who recognizes a number of divergent phyla, not here indicated)

and its rear is higher. The nostril opening has receded backward on the face, which means one of two things: either a proboscis or an adaptation to aquatic life. Here apparently the former is indicated, for the lower jaw, with its horizontal spade-like tusks, is elongating, probably for use in digging, and a proboscis is necessary to reach beyond it. The upper tusks are larger, curve downward, and bear on their outer face a band of enamel which is lacking in the modern elephant tusk, except for a tiny patch at the end which is soon worn away. The skull, jaws, and tusks of *Paleomastodon* show clearly that digging was a prime function and determined the future tendency in evolution. The grinding teeth are not unlike those of *Moeritherium,* although somewhat more complex. *Paleomastodon* was elephant-like in body, so far as we know, although in neither of these Faiyum forms was the entire skeleton discovered. It stood, perhaps, three and a half feet in height.

The Four-tuskers

Out of the *Paleomastodon* comes a form variously known as *Tetrabelodon* or *Trilophodon,* the former in allusion to its four tusks, the latter to the number of cross crests on its intermediate grinders. The skull is large with well developed diploë, and the tusks, while resembling those of *Paleomastodon,* are much longer and still possess the enamel band. But the lower jaw is unique in its great length, especially at the point of union of the two halves which bore the usual spade-like tusks. With the elongation of the jaw and the increased stature of the animal came the corresponding development of the trunk. This could be raised and swayed from side to side, but the jaw still impeded its full use, as compared with that of existing elephants.

A large specimen of *Trilophodon angustidens* from the Miocene bed of Gers, France, may be seen in the Paris Museum of Natural History. It was nearly as large as the Indian elephant. Trilophodons were great migrants, spreading to Europe, India, and even to North America, arriving there early in Miocene time. They gave rise in turn to other four-tuskers, of which *Tetralophodon lulli* from Nebraska possessed a jaw over six feet in length! The jaw having reached the maximum length commensurate with utility, now shortens again and ultimately loses

its tusks, a short, spout-like process on the chin of the modern elephant being its final vestige. With the shortening of the lower jaw the upper tusks curve upward instead of downward, the enamel band being retained in *Dibelodon* and lost in the true mastodons and elephants. The shortened jaw liberated the trunk to full utility.

As with the horses, the proboscideans are not a single evolutionary line; for there arose during Pliocene and Pleistocene times upward of a dozen divergent races which throve for a while then died out, except for the two existing elephant species. One of these was *Dibelodon,* with short jaws and enamel-banded tusks, and which survived in South America until recently.

The American Mastodon

The true mastodon, *Mastodon americanus,* came from the Old World, but survived in the New until possibly within the last thousand years or so. This was a stocky animal, up to nine feet five inches high, with large, enamel-less tusks and comparatively simple molars. The latter had four or five cross crests, open in character, with little or no cement on the crown, and two at a time in either jaw, or eight all told. The teeth indicate a forest and savanna dwelling animal.

Adaptations Among Elephants

True elephants passed through transitional stages in the evolution of their molars. The stegodonts had more numerous cross crests than the mastodon; the valleys between gradually became filled with cement and the crests increased in number until the condition of the true elephant grinder was reached. *Stegodon* was Asiatic, while *Elephas* was distributed over Asia, Europe, and America, the somewhat more primitive African elephant being called *Loxodonta,* from the lozenge-shaped character of the molar crests.

All of these elephants have upturned, spiral, enamel-less tusks and short lower jaws. These tusks are larger in *Loxodonta* than in *Elephas*—in fact there is a tendency on the part of the modern Indian elephant toward the entire elimination of these once useful organs.

Elephants in North America

During Pleistocene time there were three more or less related species of true elephants in North America, exclusive of the mastodon. Of these the earliest was the Imperial elephant which stood at least thirteen feet six inches at the shoulder, and whose spiral tusks, which sometimes crossed at the tips, measured thirteen feet to sixteen feet on the curve. In this elephant the molars were coarsely ridged and had a thick coating of cement. This species, *Elephas imperator,* is also known as the southern mammoth and ranged from California to Texas and Mexico. One tooth is recorded in French Guiana, which seems strange, for no other true elephant is known in South America.

Elephas columbi, the Columbian elephant, is intermediate in distribution as well as in evolution between *imperator* and *primigenius,* the woolly mammoth, although its range to some extent overlaps that of the other two and its teeth and other characteristics seem to merge into those of the mammoth. In old males it also possessed huge, spiral tusks which overlapped at the tips. Its fragmentary remains are abundant throughout the middle latitudes of the United States, but rarely does one see a mounted skeleton of either *columbi* or *imperator.* The Columbian elephant, with its eleven foot tusks stood over ten feet, exceeding slightly the living Indian elephant but not equaling the African.

The Woolly Mammoth

The woolly mammoth is the most picturesque and perhaps the best known of all prehistoric animals, for not only are its frozen carcasses preserved to us, but it was seen alive and depicted with admirable fidelity by the Paleolithic artists of Europe. The mammoth was circumpolar in distribution, and its abundant fur adapted it for life amid glacial and arctic cold. Judging from the perfection and profusion of its remains, the mammoth, like the American mastodon, must have vanished from the land of the living in comparatively recent times. Contrary to the impression gained through our use of the term mammoth, *Elephas primigenius* was not a large animal as elephants go, nine feet three inches being

the maximum recorded height. The teeth were fine, with many crests; in fact they possessed the greatest number in any species, implying the final perfection of these complex organs. The tusks, however, are of two sorts: huge, spiral ones and short, nearly straight ones. This difference may either be a sex, age, or varietal variation, but was probably the first.

The Tallest Elephant

Elephas antiquus, the straight-tusked Mid-Pleistocene elephant of Europe, had the greatest stature among proboscideans, for it stood nearly fifteen feet in height, surpassing the great African "Jumbo" by four feet.

A strange proboscidean of Miocene and Pliocene time in Europe was *Dinotherium,* elephant-like in body and limbs, but with extremely simple molars implying its descent from a form not later than *Paleomastodon,* and probably earlier. The remarkable feature, aside from the apparent total loss of upper tusks, was the lower jaw, which was bent sharply at the front and possessed a pair of curved tusks which pointed directly downward. *Dinotherium* has given rise to much conjecture, especially as to its habits of life. The general feeling is that it was largely swamp-dwelling and used the tusks to dislodge its food. One amusing notion was that *Dinotherium* was aquatic, lived in rivers, and at night anchored itself to the bank with its tusks in order to sleep comfortably.

Summary

Thus the fossils tell us of the origin of the proboscideans out of an ancestry common with the conies of Syria and Africa and the sirenians or sea cows, of their first appearance in *Moeritherium* of Egypt, of the successor *Paleomastodon* also of Egypt, of their migration to Europe where the four-tuskers throve, and of their subsequent migrations the world over, excepting to Australia, Eurasia being the chief center of dispersal.

We see the grinding teeth increasing in complexity, except in *Dinotherium* and *Mastodon,* and the second incisors of both jaws developing into digging organs, the upper downwardly curved, analogous to a pick, the lower to shovels. With the development of the latter came the elongated nose and upper

lip which were to form the proboscis. After reaching a mechanical limit of utility, the lower jaw turns downward, as in *Dinotherium,* or shortens, as in all the other phyla. In the first the upper tusks disappear, in the others they turn upward, becoming in extreme cases huge spiral organs which crossed at the tips. Accompanying all this was the heightening and shortening of the skull, for leverage, and a vast increase in bulk, until they in turn become the largest of terrestrial mammals, as the dinosaurs were the greatest among terrestrial reptiles, although the former never equaled the latter in total tonnage; that has only been attained and surpassed by the whales. It is interesting, however, that, as with the horses, while many splendid lines have passed away forever, a few remain for the interest and utility of mankind.

CHAPTER IX

FOSSIL MEN

It is strange how ready the average man is to accept as facts the existence and interpretation of fossils as long as they pertain to other animals or to plants, but how extremely skeptical he can be when fossil man is mentioned. This is due in part to prejudice, whether inspired by religious beliefs or by plain egotism, and also because of the extreme rarity of actual fossils, especially in this country. In Europe one may go to each of several museums—the British Museum in London, the museums in Paris, Berlin, Bonn, and Heidelberg among others—where he may see for himself the actual relics. But in America these are necessarily illustrated by casts and reconstructions, all of which are apt to inspire disbelief, rather than conviction, on the part of the skeptical. This is due, of course, to the unique character of most of the material and the consequent fact that they are so valued that American money cannot tempt the European museum authorities to part with a single specimen. But to one who has seen and handled them these relics are as real and authentic as are the fossil remains of any other forms of life, and they are just as replete with information.

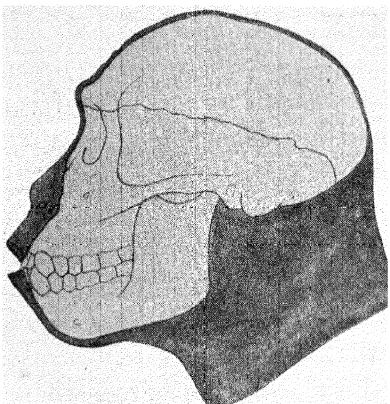
Fossil men have been found in China, Java, and South Africa, but chiefly in Europe. They have been discovered in the river drift, the sedimentation of such streams as the Elsenz in Germany and the Ouse in southeastern England, and in limestone caverns in various parts of France, Spain, Belgium, Germany, and Austria. The former are the result of accidental inclusion, possibly of drowned victims, the latter often are the result of intentional burial in the deposits on the cavern floor.

In order of their antiquity, regarding which there is difference of opinion, the following discoveries of fossil species belonging to the Hominidae, or family of men, may be mentioned:

The Ape-Man of Java

(Figure 54)

Pithecanthropus erectus, the ape-man of Java, was discovered in 1891-1892, in the river bed of the Sula Bengawan near Trinil, Java. There were probably two individuals, one represented by the skull cap or calvarium, three teeth, and a left thigh bone, the other, found some miles away, consisting of a portion of the lower jaw. Their age is about 500,000 to 1,000,000 years.



(*Pithecanthropus erectus*)

This species, while in a sense annectant between man and the apes, is not supposed to be in the main line of ascent, but a form pushed to one side from the original Asiatic birthplace of mankind, to endure for a while, and then to suffer extinction as an evolutionary race

From a restoration by the author, after McGregor

Pithecanthropus possessed a low skull vault with immense beetling brows and a cranial capacity about two-thirds that of modern man. The thigh, however, was straight, and indicates how long erect posture has been a trait of mankind. This ape-man was not in the main line of ascent but was a form pushed aside from the original Asiatic birthplace of mankind, to endure for a while, and then to suffer extinction as a race.

The Heidelberg Man

(Figure 55)

Homo heidelbergensis, the Heidelberg man, was found in 1907 in the river sands at Mauer, Germany, near the town whose name it bears. This fossil consists of a perfect lower jaw with complete dentition, and its age is estimated at about 400,000 years.

The Heidelberg man, also, possessed a massive, ape-like jaw, but essentially human teeth. More of the skeleton has not yet been revealed, but he was doubtless ancestral to the Neanderthal man and must have possessed a comparable, although somewhat more primitive cranium, as the conjected restoration shows.

The Piltdown Man

(Figure 56)

Eoanthropus dawsoni, the Piltdown man, from the river drift in the valley of the Ouse, Sussex, England, was discovered in 1912. Again there were two specimens, found some four miles apart, the first including portions of the skull and teeth, together with the left half of the lower jaw. The second specimen, much less perfect, served to corroborate the association of the human cranium with the ape-like lower jaw, about which there had been considerable difference of opinion. Their age is 275,000 to 400,000 years.

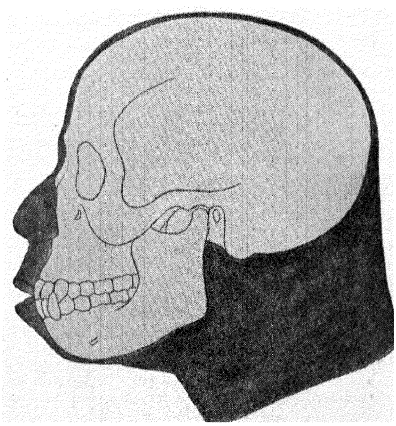


Fig. 56—THE PILTDOWN MAN
(*Eoanthropus dawsoni*)

The skull is superficially of man-like appearance, although it is also ape-like, especially in the rear and in the inward slope of the sides. The contained brain, however, is not only small, but the most primitive and ape-like one hitherto recorded

From a restoration by the author, adapted from McGregor

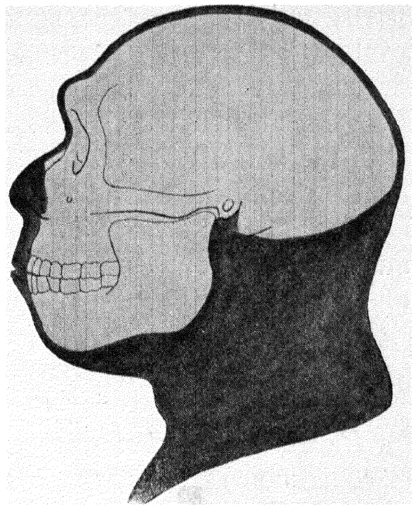


Fig. 55—THE HEIDELBERG MAN
(*Homo heidelbergensis*)

This species seems to be in the line of ascent with the Neanderthal man of later time

From a restoration by the author, adapted from McGregor

The Piltdown man had a high, steep forehead without beetling brows, so that while the cranium was quite man-like, the jaw, on the contrary, was ape-like, as was also the brain. We cannot as yet visualize the whole of the Piltdown man.

The Peking Man

Sinanthropus pekinensis, the Peking man, came from cave deposits at Chow Kow Tien, twenty-five miles southwest of Peking (Peiping), China. In 1921 two teeth were discovered, and in 1930 a fine calvarium* and other

* Calvarium, the domelike upper portion of the skull.

parts, and later another skull, were brought to light, but the explorations are not yet complete and will undoubtedly yield further material. Their age is difficult to determine; but from the associated fossil animals they were possibly contemporaneous with the ape-man of Java and the Piltdown man. The Peking man is also of the Neanderthal type, with its beetling brows.

Then, after a lapse of thousands of years, come the cave men of Europe and Africa, including the most completely known of fossil men. These are:

The Neanderthal Man

(Figure 57)

Homo neanderthalensis (or *primigenius*), the Neanderthal man, is known also as the Mousterian man from his stage of culture. The first discovery was made at Gibraltar in 1848. Others were made at: Neanderthal, Germany, in 1857; Spy, Belgium, in 1886; and at a number of other localities, including Chapelle aux Saints, and Aix la Chapelle, Gibraltar, and finally in 1924, 1931, and 1932 in Palestine. Altogether there are some forty individuals showing racial distinctions within the species. Their age is estimated at 25,000 to 40,000 years B.C.

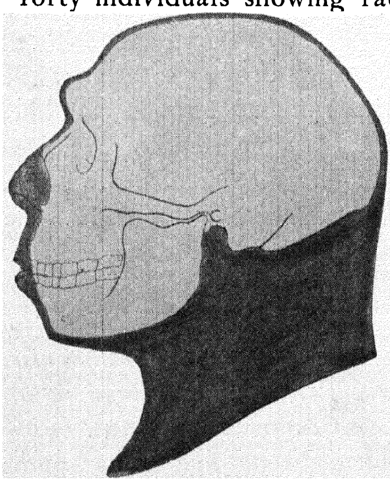


Fig. 57—THE NEANDERTHAL MAN
(*Homo neanderthalensis*)

One of the best known of fossil men. He was probably the culminating member of a long-lived race which, as such, has ceased to be

From a restoration by the author, adapted from McGregor and Boule

Neanderthal man is now one of the best known of fossil men, and we can visualize him in his entirety. He was short of stature, stocky, but with a slouching gait and a huge bestial head thrust forward, with low skull vault and beetling brows. He seems to have been the culminating member of a long-lived race which as such has ceased to be, although because of possible crossing with Crô-Magnon man, some of his blood, greatly diluted, may still exist. He had fire and practiced reverential burial, which seems to imply

some conception of existence beyond physical death, whatever the form of that concept may have been.

The Rhodesian Man

(Figure 58)

Homo rhodesiensis, the Rhodesian man, from a cavern at Broken Hill mine in northern Rhodesia, Africa. Here again two specimens were discovered in 1921, one of which is a splendid skull with complete dentition and other parts but no lower jaw. The Rhodesian man cannot be dated with accuracy but is fully fossilized and "of respectable antiquity." He also had beetling brows and belonged to the Neanderthal group.

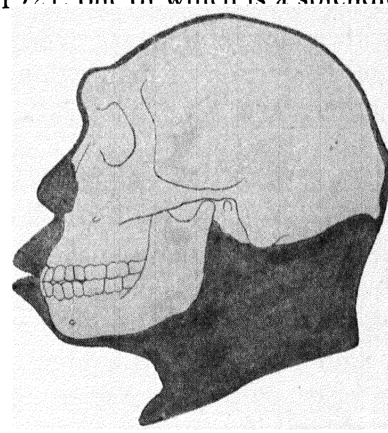


Fig. 58—THE RHODESIAN MAN
(*Homo rhodesiensis*)

This fossil man was found in association with animals which are either now alive in Africa, or were alive at the advent of the big-game hunters, and this seems to imply a comparatively recent date

From a restoration by the author, after Smith Woodward

Modern Man

(Figure 59)

Homo sapiens is the existing species to which all men and women belong, of whatever race, from the highest to the lowest. Of this species the oldest race is that of Crô-Magnon man discovered in Gower, Wales, in 1823; at Aurignac, France, in 1852, and especially the type material at Crô-Magnon, Dordogne, France, in 1868. It is a widespread variety of which many perfect specimens are known and which lived in Europe as far back as 25,000 B.C.

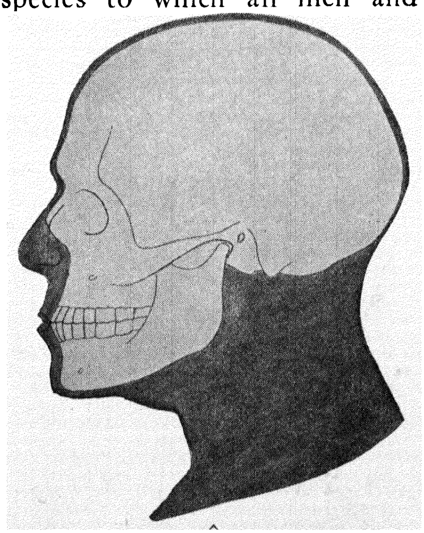


Fig. 59—THE CRO-MAGNON MAN
(*Homo sapiens*)

Crô-Magnon man may well be called the summit of human evolution. All his features are diagnostic of our species in its finest expression

From a restoration by the author, after McGregor

Crô-Magnon man may well be called the summit of human evolution. Averaging over six feet in height, erect of carriage, and with a splendid head, this man must have looked with disdain upon the Neanderthals whose distribution in time and space he overlapped. The beetling brows are gone, the forehead is high, the chin jutting and pointed; all his features are diagnostic of our species in its finest expression.

The above is a very impressive list and compares favorably with many another group of fossil organisms both as to variety and perfection of material, and is worthy of the utmost respect and credence.

Whence Came the Fossil Men of Europe?

It is supposed that the fossil men of Europe represent a series of invading waves along several corridors of migration from their racial homes in Asia, for the evidences point strongly to Asia rather than to either Europe or Africa as the place of origin of the human family.

For a detailed account of human origins see "The Coming of Man" in this *Series*.

CHAPTER X

EXTINCTIONS AND THEIR CAUSES

WE HAVE spoken several times of the extinction of various forms of life. The older authorities who accepted the doctrine of creationism could not understand how any race of animals created directly by the Almighty could possibly have passed out of existence unless destroyed by the hand of man, for even if animals represented by fossils in a given locality were no longer in existence in that particular region, there was no proof that they did not still exist in some unknown portion of the globe. Thomas Jefferson, the third president of the United States, wrote the first paper on paleontology published in America. This paper, which appeared in 1799, was entitled "A Memoir on the Discovery of Certain Bones of a Quadruped of the Clawed Kind in the Western Parts of Virginia." This creature Jefferson took to be some gigantic cat-like animal which he named *Megalonyx* in allusion to its great claws and believed to be yet alive in the fastnesses of Virginia. The world has been so thoroughly explored now that the discovery of a large unknown terrestrial mammal is a very remote possibility, the curious Okapi, a giraffe-like form from Central America, announced by Sir Harry Johnston in 1901, being the last such discovery. Hence one is justified in the assumption that many magnificent types among animals, as well as countless obscurer forms, have utterly passed away. Perhaps the first real recognition of this extinction was made by the French naturalist, Georges Cuvier; in explanation of the fossil animals from the gypsum quarries he invoked the theory of Catastrophism.* We know that several forms of life have been locally destroyed by man, as the wolves and boars in England, and we also know that in some cases man has been responsible for total extinctions, as in the case of the passenger pigeon, the dodo, the great

* See page 31 in "The Earth" in this *Series*.

auk, and Steller's sea cow. We are also aware that, unless preventive measures are speedily taken to avert it, the racial life of the great whales will soon cease, as an outcome of the relentless slaughter of the Antarctic fisheries. We, as scientists, are just as fully convinced of extinctions through natural causes.

Two Forms of Extinction

Extinctions are of two sorts which may be compared to the death of two men, one a celibate, the other not. Both have received their life and heritage through an unbroken line from the beginning of life on earth, but for the celibate who dies without issue, his line ceases forever, while the other, although as an individual he has ceased to be, yet lives in his children. Extinction can be by *racial death,* comparable to the celibate, or by *transmutation,* where a species as such has ceased, but its blood still flows in the veins of its altered descendants.

There were, during Miocene time, as we have seen, several lines of horse evolution, two of which are represented by *Hypohippus,* the browsing horse, and *Merychippus,* the first true prairie horse. *Hypohippus* was the celibate race which died utterly and out of which no new equine genus arose; *Merychippus,* on the other hand, was immortalized in its descendants, for, through *Pliohippus* and *Plesippus,* it gave rise to *Equus* which still survives, although not in the form of *Merychippus,* for that animal is, from the standpoint of immediate existence, just as extinct as the other. The word transmutation is more or less synonymous with evolution, so that a discussion of the causes leading to *Merychippus* extinction would embrace a discussion of the entire problem. With *Hypohippus,* on the other hand, if any single cause would suffice, it would be Miocene aridity with a lessening of the sort of vegetation to which its short-crowned, browsing teeth were adapted, with consequent racial starvation. In general, although environmental change is in the main a prime cause of extinction of either sort, one is in error if he is content with so simple an explanation as that. For the environment of an animal, physical and biotic, is so complex that he is menaced upon every side, so that generally the initial cause need do no more than begin the destruction, and

when the numbers are reduced beyond a critical point extinction is sure to follow.

CHANGES IN PHYSICAL ENVIRONMENT

Dr. Osborn has summarized the causes of racial extinction, his study of the problem being based on both existing and fossil forms, but largely the latter. First in importance are changes in the physical environment wrought by the elevation and subsidence of land masses, with the resultant formation or severance of land bridges. These would either permit or inhibit migration. The first may allow the incursion of hostile animals into an environment, to the detriment of the native population. The second may result in increased competition which the weaker forms could not resist. On the other hand, isolation may permit forms to survive long after their extinction elsewhere, as in the case of the Australian marsupial fauna.

Increasing cold has been a very potent cause of extinction, for while some vigorous animals, like the musk ox, may be able to adapt themselves to it, others will fail to do so. Its reaction on cold-blooded air-breathers—amphibians and reptiles—is obvious. Increasing moisture changes the face of nature, producing more swamp and jungle and the number of insect pests which may be the transmitters of disease. It would cause the diminution of the grassy steppe-like lands, and thus be inimical to horses and other grazing forms, just as the spread of the prairies due to increasing aridity would affect the browsers. A specific instance of the result of widespread aridity would be the extinction of early primates in North America, at the close of the Eocene period. Now, except for mankind, there are no primates found north of the edge of the Mexican plateau, although south of it, where the climate changes abruptly into the warm, moist conditions of the tropics, they are still abundant and are the actual descendants of those which formerly lived farther to the north.

CHANGES IN BIOTIC ENVIRONMENT

Competition is inseparable from life and is a potent stimulus to evolution, but the competition caused by the incursion of new adaptable forms may, as we have seen, prove fatal to the inadapt-

able. Restrictions of island life with reduced food supply has seemingly been the cause of racial dwarfing, as the Shetland ponies or the dwarf elephants found as fossils in the islands of Cyprus and Malta in the Mediterranean. Introduction of destructive grazing animals and rabbits, or of such carnivores as the Dingo dog into Australia, may render extinct many of the ancient fauna, either indirectly through diminution of the food supply or through direct destruction.

Internal Causes

There are also internal causes, such as the inadaptive feet, teeth, and brain of the archaic mammals. Large size and slow maturity, together with few young, may make competition with smaller, highly prolific animals unendurable. Thus, as Dr. Osborn has said,* by way of summation: "Following the diminution in number which may arise from a chief or original cause, various other causes conspire or are cumulative in effect. From weakening its hold upon life at one point an animal is endangered at many other points."

**American Naturalist*, vol. XL, page 859.

CHAPTER XI

THE UTILITARIAN VALUE OF FOSSIL REMAINS

As we have seen, fossils are of prime importance in determining the age of the strata wherein they are found, and while, from the standpoint of the man of business, this may seem of little practical moment, other than its educational value, it is nevertheless indirectly of the greatest use.

Fossils an Index to Oil and Coal

Two of the most important mineral substances, both of which are of organic origins, are oil and coal. Oil geology, to determine whether or not a certain area would be productive and therefore pay for the expense of elaborate drilling, depends in part on structure of the earth's crust, but more and more is it dependent upon the fossils themselves. For oil may be found in strata of certain geologic periods, whereas others are invariably barren. Should certain strata prove oil-bearing in one region, it is necessary to determine what is known as correlation in another region in order to predict the possibility of the occurrence of oil there. Not only have the larger fossils proved of value as correlators, but the micro-organisms, such as the tiny shells and tests of Foraminifera among the Protozoa, have proved to be splendid index fossils. Hence in well-drilling the cores are carefully examined and not only the contained microfossils but the order of their occurrence determined. A drilling from the new site, if it compares in its fossil contents with that from the old, will form a basis for an estimate of yield and consequent values. A paleontologist, especially one familiar with the technique of core determination, is today an essential part of the organization of every oil company.

In a similar manner, both large and small fossils are used to follow productive coal seams. Profitable coal beds would not be found associated with Silurian fossils; on the contrary, certain

Cretaceous fossils would at once indicate the likelihood of coal-bearing strata. The same is true of other mineral products, iron ore, building stone, and the like.

A Legal Illustration of Fossil Importance

A single case will illustrate the use of fossils in a legal sense. "New York State once called for estimates on the construction of a section of highway, stipulating that samples of the stone to be used be submitted with the estimates. A certain contracting company submitted a satisfactory estimate and produced specimens of a stone of high quality. The contract was signed and the road building began. When the work was finished, it did not give satisfaction and the State refused payment on the ground that the contractors had used a grade of stone inferior to that agreed upon. The contractors sued the State for their money; but, unluckily for them, the sample they had submitted with their original estimate contained a fossil which fixed its geological age exactly. The State was able to prove that no rock of that age existed in any of the quarries from which the contractors had obtained the stone they finally used. One fossil cost the contractors dearly." (C. P. Berkey, in *Geology from Original Sources.*)

Fossils a Source of Petroleum*

According to our original definition of a fossil, it may be either the actual animal or plant, or the product of the activity of the organism. Although in a strict sense the various hydrocarbons are not in their original recognizable shape, yet they are organic products and as such approach near enough to our subject to be worthy of mention. They include natural gas and petroleum as well as the various coals, from peat to anthracite and graphite. The coals are clearly of plant origin, while oils and gas may be either animal or plant products.

When organic beings die and decay sets in, the resultant materials are returned to the air or the dust of the earth, if the disintegration takes place while exposed to the atmosphere. Hence pure continental deposits contain little or no commercial petro-

* Adapted from Pirsson and Schuchert, *Text-book of Geology,* volume 2, page 254.

leum unless it has seeped into them from adjacent oil-bearing strata. When water-borne sediments, whether of fresh or marine origin, are subject to repeated weathering during their deposition, the contained hydrocarbons are oxidized, and hence they, too, lack paying quantities of oil. That this has happened is indicated by the color of the strata, red or reddish, yellowish or white, and by the presence of meteorological records such as rain prints or sun cracks.

Under water, especially of the sea, not only is the disintegration of the organism slow, but the fats are liberated as tiny oil droplets which rise to the surface and are lost in clearer waters, particularly if the latter are in motion, for this assists oxidation. If, on the other hand, the waters are muddy and still, the oil droplets will adhere to the mud particles and thus sink to the bottom and be buried by subsequent material and hence preserved. This deposited mud ultimately forms dark bituminous shales, the darkness of their color indicating the presence of oil. These black shales, although forming a small percentage of the shales as a whole, are nevertheless the "mother rocks" of petroleum, which may be extracted by distillation. The natural liberation of the petroleum into pockets of fluid oil and gas is evidently due to the pressure of capillarity which sets the oil free.

Our whole civilization in this so-called "machine age" is based largely upon these hydrocarbon products of bygone animals and plants, which form the chief motivating agent of the present time. Their value to mankind is therefore inestimable.

SUGGESTIONS FOR FURTHER READING

Prepared by the Author

GEOLOGY FROM ORIGINAL SOURCES—*William M. Agar, Richard F. Flint* and *Chester R. Longwell* HOLT
A collection of collateral readings presented in an extremely interesting and original manner.

THE EVOLUTION OF THE EARTH AND MAN—*George A. Baitsell* YALE
A collection of essays upon the evolution of the earth and its inhabitants including mankind, written by twelve men each of whom has specialized along the subject of his essay. Particular attention is called to Chapter II, by Charles Schuchert, on "The Earth's Changing Surface and Climate," and Chapters IV and V on "The Pulse of Life" and "The Antiquity of Man" by R. S. Lull.

THE EVOLUTION OF THE HORSE—*Frederic B. Loomis* JONES
A fully illustrated book, by a practical paleontologist, on the origin and history of the horse.

ANIMALS OF THE PAST—*Frederic A. Lucas* AMERICAN MUSEUM
Charmingly written by one who not only knew his subject but through long experience knew how to present his facts to the layman.

TRIASSIC LIFE OF THE CONNECTICUT VALLEY—*Richard S. Lull*
Bulletin No. 24 of the Connecticut State Geological and Natural History Survey. An illustrated discussion of the footprints and skeletal remains of the creatures which populated the Connecticut Valley during the Age of Reptiles.

ORGANIC EVOLUTION—*Richard S. Lull* MACMILLAN
A fully illustrated textbook of evolution. Part III deals particularly with the evidences for evolution derived from the fossil record.

THE WAYS OF LIFE—*Richard S. Lull* HARPER
An expansion of the theme of "The Pulse of Life" in *The Evolution of Earth and Man.*

ANCIENT MAN—*Richard S. Lull* DOUBLEDAY
One of the *Humanizing of Knowledge* series, dealing principally with fossil human species.

HUMAN ORIGINS—*George Grant MacCurdy* APPLETON
One of the most highly authoritative books on this subject in the English language.

THE LIVING PAST—*John C. Merriam* SCRIBNER'S
A small book of essays on paleontological subjects, one of which discusses the remarkable tar pits of Los Angeles.

MEN OF THE OLD STONE AGE—*Henry F. Osborn* SCRIBNER'S
Fully illustrated from first hand sources.

ORIGIN AND EVOLUTION OF LIFE—*Henry F. Osborn* SCRIBNER'S
A learned volume based in large part upon the fossil record. Time and opportunity have given Professor Osborn an insight into this field possessed by few men.

TEXTBOOK OF GEOLOGY: PART II, HISTORICAL GEOLOGY—*Charles Schuchert* WILEY
A fine exposition of prehistory from stratigraphical and fossil evidence, by a high authority.

THE EARTH AND ITS RHYTHMS—*Charles Schuchert* and *Clara M. LeVene* APPLETON
An eminently readable book produced "by the process of filtering a great mass of geologic detail through a non-scientific mind."

AN INTRODUCTION TO THE STUDY OF FOSSILS—*Hervey W. Shimer* MACMILLAN
A valuable textbook of paleontology interpreted through the study of existing forms.

TEXT-BOOK ON PALEONTOLOGY—*Karl A. von Zittel* MACMILLAN
Translated and edited by Charles R. Eastman in collaboration with a corps of seventeen specialists. Still the standard textbook of paleontology.

KEY TO PUBLISHERS

AMERICAN MUSEUM—American Museum of Natural History, Columbus Avenue and 77th Street, New York, N. Y.
APPLETON—D. Appleton & Company, 29-35 West 32nd Street, New York, N. Y.
DOUBLEDAY—Doubleday, Doran & Company, Garden City, N. Y.
HARPER—Harper & Brothers, 49 East 33rd Street, New York, N. Y.
HOLT—Henry Holt & Company, Inc., 1 Park Avenue, New York, N. Y.
JONES—Marshall Jones Company, 212 Summer Street, Boston, Mass.
MACMILLAN—The Macmillan Co., 60 Fifth Avenue, New York, N. Y.
SCRIBNER'S—Charles Scribner's Sons, 597 Fifth Avenue, New York, N. Y.
WILEY—John Wiley & Sons, Inc., 440 Fourth Avenue, New York, N. Y.
YALE—Yale University Press, 143 Elm Street, New Haven, Conn.

GLOSSARY

[Only those terms are defined in this glossary which either are not explained in the text or are explained once and are used again several pages away from the explanation.]

ARTICULATION: a state of being joined.
ARTIFACT: a product of human workmanship.
COPROLITES: a fossil excrement.
HORIZON: the deposit of a particular time, usually identified by distinctive fossils.

INDEX

WITH PRONUNCIATIONS †

† For key to pronunciation, see page 114.
* Asterisk denotes illustration.

Key to Pronunciation

ā as in dāy	ē as in mēte	ī as in tīme	ŏ as in nŏt
ȧ " " senȧte	ê " " êvent	î " " îdea	ô " " lôrd
ă " " ădd	ĕ " " ĕnd	ĭ " " ĭll	
â " " câre	ẽ " " tẽrm	ĩ " " fĩrm	ū " " ūse
ä " " fär	ġ = j (gentile)	ō " " ōld	û " " ûnite
ȧ " " lȧst	ḡ as in get	ô " " ôbey	ŭ " " ŭs
			û " " tûrn